EASTERN EQUATORIAL PACIFIC PRODUCTIVITY VIA TWO GEOCHEMICAL PROXIES

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ABSTRACT

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Drivers that influence oceanic productivity are not clearly constrained. However, sea level changes during glacial cycles have been proposed as a potential driver for productivity variations observed over warm and cold climate periods. In order to determine this, additional oceanic paleoproductivity data collection is necessary to estimate the ocean's feedback in response to a dynamic climate. The eastern equatorial Pacific (EEP) is an ideal site for productivity studies due to its high levels of nutrients and deep upwelling. This research examines the phosphorous and barite geochemisty of four EEP sites while also comparing the sites' glacial and interglacial productivity variations to the geochemistry and productivity results of an independent central equatorial Pacific site.

Phosphorus and other elemental data were collected from sites 845, 848, 849, and 853 (ODP Leg 138). Using a Ba/Ti and P/Ti proxy ("excess" proxies), distinct productivity variations during glacial and interglacial periods was observed. While the age model for these sites has been estimated, the observed variations more than likely agree with high productivity during glacial periods and lower productivity during interglacial periods. Central equatorial Pacific cores RR0603-03TC and RR0603-03JC (IODP site survey cruise for Proposal 626) have been used as a reference for geochemical concentration parameters, as well as a comparison tool for productivity variations among the central and eastern sites. The central equatorial geochemistry results provided

support for sea level changes driving paleoproductivity variations. The similar variation patterns displayed by the EEP's geochemical data in this research could provide additional support for this hypothesis.

Gabriel M. Filippelli, Ph.D., Chair

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Introduction

The driving mechanism controlling paleoproductivity spanning the Pleistocene epoch is not clearly constrained. The glacial Shelf-Nutrient Hypothesis (SNH), first proposed by Broecker (1982), has resurfaced as a potential explanation for paleoproductivity variations observed on glacial and interglacial timescales. Delineating oceanic physical, chemical, and biological processes driving these past variations is necessary for aiding the prediction of future oceanic behavior in response to a warming climate.

The SNH is used to explain why productivity has increased during glacial times due to the loss of the continental margin sinks for nutrients (Broecker, 1982). This theoretical positive-feedback mechanism hypothesizes that lowered sea level resulting from increased glacial ice accumulation allows this marginal loss to become a direct pathway for transfer of eroded nutrients, i.e. phosphorus and nitrogen, to the deep ocean (Broecker, 1982) (Fig 1). This change in deposition due to sea level variations is hypothesized to drive productivity fluctuations on glacial and interglacial timescales (Fig 2). Recently, Filippelli et al. (2007) proposed that changes in the oceanic phosphorus (P) mass balances caused by glacial sea level changes may be a potential driver for productivity variations. Due to new estimates of a shorter response time for P cycling based on geochemical analysis conducted on eastern equatorial Pacific (EEP) and south Atlantic ocean sediments, Filippelli et al. (2007) provides convincing support for the potential of sea level changes driving paleoproductivity variations on glacial timescales.

This study focuses on the geochemical analysis of four EEP sites for the purpose of determining paleoproductivity variations along a productivity transect spanning regions of high to low productivity in the modern ocean (9^{o}N to 2S; 94^{o}W to 139^{o}W Fig 3). These variations are then evaluated on glacial timescales. In order to apply these findings on a current scale, modern ocean productivity values are then used as a comparison tool to evaluate correlations with each site's paleoproductivity.

Background

The primary objective of Ocean Drilling Program (ODP) Leg 138 was the acquisition of high-resolution records of climatic change in the equatorial Pacific (Mayer *et al*., 1992). Sites 845, 848, 849, and 853 of ODP Leg 138 were collected in May and June of 1992 and sub-sampled for this study in August 2007 at the University of California at Santa Cruz (Fig 3). Site 845, a low productivity basin, is the most northeastern site of the Leg. While not a part of the transect, site 845 still remains within the high productivity area. The other three sites vary slightly with respect to latitude but are all positioned at approximately 110^{o} W.

When analyzing factors that potentially contribute to productivity variations, the underlying focus is the oceanic carbon cycle. The connection between carbonate cycles and climate change over glacial timescales is unknown; however, climate transitions are thought to be potentially driven by changes in carbonate dissolution, changes in productivity, or a combination of the two (Farrell, 1989). Because carbonate productivity determines deep sea carbonate input, understanding the drivers of productivity will then indirectly provide insight into carbonate cycles influence on climate change (Farrell, 1989).

The proxies used in this study, P/Ti and Ba/Ti, are indirect methods of calculating export production within each site. Ti has a strong relationship with biogenic sediment (Murray, 1993; Wefer *et al*., 1999). This indicates that removal of biogenic associated Ti leaves surface productivity as the export production result.

Glacial Shelf Nutrient Hypothesis

Broecker (1982) first proposed the shelf nutrient hypothesis which suggests a positive feedback loop that incorporates glacial ice volume, sea level, shelf exposure, and changes in global surface temperatures. The hypothesis states that during glacial periods, increased ice volume causes sea level to lower resulting in increased continental shelf exposure. The continental shelf, now susceptible to weathering, increases oceanic phosphate concentrations because of increased riverine flux of phosphates. More nutrients increase oceanic productivity and the amount of atmospheric CO_2 sequestered in the deep ocean. Surface temperatures decrease because of lowered atmospheric CO_2 (Fig 1).

Due to the complex biogeochemical interactions related to this hypothesis, several aspects, especially carbon transfers, have been analyzed with different proxies. For example, nutrient budgets have been examined via P concentrations and foraminifera Cd/Ca ratios (Henderson, 2002). These analyses have aided in paleophosphate concentrations but not deep ocean P budgets (Filippelli *et al*., 2007). The proxies used in this study focus on deep ocean P in order to evaluate the transfer of P to the deep ocean due to the loss of a continental margin sink.

Testing the SNH via the deep sea P budget is possible due to a few factors. The first is that estimates of P residence time have been re-evaluated from previous estimates (Filippelli *et al*., 2007). P is estimated to have a residence time of less than 20kyr. This refinement from previous estimates of approximately 100kyr now indicates that the mass balance of P is responsive within glacial timescales. Second, initial measurements of P export from the continents to the ocean on glacial timescales indicate high rates of P weathering and transfer during glacial intervals, particularly at glacial terminations and with lower amounts of P export into the deep ocean during interglacial intervals (Filippelli *et al*., 2007). The net increase of P delivered to the deep ocean during glacials would include terrigenous matter from the margin sinks (Filippelli *et al*., 2007). These findings further point to P as the driver for the biogeochemical processes.

To test the SNH, a broader suite of sampling locations including additional oceanic paleoproductivity proxy data collection is necessary. The eastern equatorial Pacific (EEP) is an ideal site for productivity studies due to its high levels of nutrients and importance in terms of burial production. Also, the EEP is a high-nutrient, low-chlorophyll (HNLC) area characterized by intense upwelling. Marine producers thrive in these areas where upwelling brings cold, nutrient rich deep water to the surface. A direct input of nutrients during glacial times enriches the deep ocean, so when upwelling occurs, the nutrient concentration brought to the surface is in abundance in these areas (Dekens *et al*., 2007).

This research examines a nutrient (P/Ti) and an inorganic (Ba/Ti) proxy of four EEP sites while also comparing the sites' glacial and interglacial export production variations to the geochemistry and productivity results of one independent central equatorial Pacific (CEP) site RR0603 as well as two previously studied CEP sites, TT013-PC72 and TT013-PC114 (Fig 3).

Site Descriptions

Characteristics such as coordinates, water current direction, water depth, core length, sample number, sedimentation rates, and lithology are described for each analyzed and comparative site. Sites are described in order of the modern ocean productivity gradient. The duration of the sedimentation rates listed is approximately 0.8Ma if not older. Site 849 is indicative of high productivity and Site 845 represents low productivity.

Site 849 (0^o10'N, 110^{o}31'W)

Site 849 is located beneath the eastward-flowing Equatorial Undercurrent (EUC), which is the warm water counter current to the Southern Equatorial Current (SEC) (Garrison, 2004). The EUC and SEC are warm water currents that generate equatorial upwelling (Garrison, 2004). The nutrients delivered to the EUC and SEC's surface currents from upwelling make this site optimal for productivity studies.

At a water depth of 3.8km, sedimentation rate remained constant, approximately 3.6cm/kyr (Mayer *et al*., 1992). From the 4.7m sediment core, 16 samples were analyzed. Due to a gap in sample collection, these 16 samples represent only the past 100kyr. While the data was not sufficient to evaluate Site 849's glacial and interglacial productivity variations, it has been documented in this study for informational purposes.

Very similar lithologically to Site 848, the sediment was composed of clayey diatom nannofossil ooze. The average foraminifer value was 25% while the terrigenous component value was less than 5% (Mayer *et al*., 1992).

Site 848 ($2^o59'$S, $110^o28'$W)

Representing the southernmost portion of the sampled transect and located beneath the westward-flowing of the SEC, Site 848 sits 3.8km below sea level (Mayer *et al*., 1992). Using Site 848's paleomagnetic record, the sedimentation rate was calculated to be 1.1cm/kyr. (Mayer *et al*., 1992). Fifty two samples at a resolution of 30cm apart were analyzed from the core's top 18m. The lithology is dominated by siliceous nannofossil and foraminifer ooze, and as well as calcareous material. In the top 18m, the percentage of foraminifers ranges from 15-45%. The amount of clay was below 18% (Mayer *et al*., 1992).

Site 853 ($7^o12'$N, $109^o45'$W)

This study site is the furthest north site in the transect and is located on the East Pacific Rise beneath the North Equatorial Countercurrent (NECC). At a depth of 3.7km, 37 samples were collected from the core's top 4m. Each sample was 15cm apart with a 0.7cm/kyr sedimentation rate (Mayer *et al*., 1992).

Sediments from Site 853 are dominated by nannofossils, clay, and foraminifers. The percentage of foraminifers ranged from 50-80%, while the terrigenous sediment averaged 25% (Mayer *et al*., 1992).

Site TT013-PC72 ($0^o11'$N, $139^o40'$W)

Collected as part of an equatorial Pacific Joint Global Ocean Flux Studies (JGOFS) cruise, TT013-PC72 (here on referred to as PC72) lies beneath the EUC at a water depth of approximately 4.3km (Murray *et al*., 2000b). At a 3kyr resolution, 314 samples were utilized from this core. From the 15.9m core, the sedimentation rate was calculated as 1.5cm/kyr. The lithology indicates an abundance of biogenic sediment, 86% CO_3, compared to the average amount of terrigenous sediment, 1.5% (Murray *et al*., 2000b).

Site RR0603 (2°55'N, 117°92'W)

Central equatorial Pacific (CEP) cores RR0603-03TC and RR0603-03JC (supplied from the AMAT03 IODP site survey cruise for Proposal 626) are used as a reference for geochemical concentration parameters, as well as a comparison tool for productivity variations among the central and eastern sites. Site RR0603-03 is 4.2km below sea level and lies beneath the EUC (Hale, 2008).

The core's lithology consists mainly of diatom nannofossil ooze. From the 11.6m collective core, 180 samples were analyzed every 7cm. The sedimentation rate was calculated to be 1.2cm/kyr and remained consistent throughout the core (Hale, 2008). This low sedimentation rate could result from RR0603-03's position atop a central Pacific sediment ridge, where biogenic carbonate is sensitive to preservation.

Site TT013-PC114 (4°04'N, 139°85'W)

Collected from the same JGOFS cruise as PC72, Site TT013-PC114 (here on referred to as PC114) lies beneath the EUC at 4.4km below sea level. From the 7.9m core, 153 samples with a 6kyr resolution were analyzed (Murray *et al*., 2000b). The sedimentation rate is approximately half (0.8cm/kyr) of Site PC72. The lithology of PC114 is similar to that of PC72 in that the composition is dominated by biogenic sediment, 79% CO_3, vs. an average of 4.5% terrigenous sediment (Murray *et al*., 2000b).

Site 845 (9°34'N, 94°35'W)

Site 845 is the northernmost site and lies west of the transect in the Guatemala Basin. This basin was sampled in order to take advantage of the significant terrigenous component expected at this site to calibrate equatorial biostratigraphies with the paleomagnetic record (Mayer *et al*., 1992). Located in the bend of the westward-flowing NECC and the north equatorial current (NEC), this site is provided with nutrient rich water from the divergence-driven upwelling that occurs between the NECC and NEC boundary (Mayer *et al*., 1992).

Sampled at 3.7km below sea level, Site 845 has a sedimentation rate of approximately 1.6cm/kyr spanning the past 1Ma (Mayer *et al*., 1992). From the 27m core, 66 samples were analyzed. Site 845's lithology is dominated by inorganic material which represents this site as a low productivity area compared to the other CEP and EEP sites. The amount of foraminifers, less than 10%, contrasts with the range of terrigenous sediments, 50-80% (Mayer *et al*., 1992).

Objectives

The data from this study will be compared with the geochemical results of the RR0603 site survey and sites PC 72 and 114, to evaluate the SNH. This study is part of several ongoing projects designed to gain a broader understanding of how the EEP has responded over time to carbonate and productivity changes.

The objectives of this study include using two proxies (P/Ti and Ba/Ti) to determine export production on glacial timescales and how that compares to modern ocean productivity, comparing the export productivity records of three other central equatorial Pacific sites (RR0306, PC72 and PC114), and determining if export productivity records from the four EEP sites supported the SNH.

Methods

Sample preparation

Approximately 240 samples total, sub-sampled at approximately 18kyr resolution spanning the last 1Ma were used in this study. Total elemental concentrations were determined after total acid digestion via a CEM MDS-2000 microwave. The liquid digests were then analyzed using a P950 Inductively Coupled Plasma - Atomic Emission Spectrometer (ICP-AES) with a CETAC AT5000+ Ultrasonic Nebulizer. The microwave digestion and ICP-AES methodologies followed in this study mirror those applied to the RR0603 samples (Hale, 2008). The nutrients and metals analyzed include P, Ca, Al, Ba, Ti, Fe, Mg, Mn, S, Sr, and Zn. National Institute of Standards & Technology (NIST) Standard Reference Material (SRM) 1646a, estuarine sediment, was used to evaluate analytical reliability. The certified value for P is 0.027±0.001, represented as a percent mass fraction, and the certified value for Ti is 0.456±0.021mg/kg. The noncertified value for Ba is 210mg/kg.

Proxy usage

The chosen proxies, P/Ti and Ba/Ti, were used to determine export production variations over time at individual sites. Because no single proxy can accurately measure export production, the use of multiple proxies allows for slightly different aspects of export production to be traced (Murray *et al*., 2000). Elements P and Ba were chosen due to their known affiliation with export production. To account for terrigenous (i.e. not biologically associated) phases, P and Ba were normalized using Ti. Normalized elements now have the terrigenous components removed thus leaving excess biogenic P and Ba expressed as ratios. P/Ti and Ba/Ti are now an indirect measurement indicative of export production.

Age model estimation

Based upon extrapolation of post ship-board data, age models were determined for each site. Age control points were provided by calcareous nannofossil events (Mayer *et al.*, 1992). Constant sedimentation rate between the age control points were assumed, which allowed individual ages to be assigned to each sample. The age model for RR was constructed from $\delta^{18}O$ analysis performed at University of California at Santa Cruz (Hale, 2008).

Glacial period designation

Two options for glacial period representation are using glacial terminations or marine isotopic stages (MIS). The MIS designation separates the Pleistocene record into "glacial" and "interglacial" intervals. Terminations on the other hand highlight approximately the last 10kyr of a glacial cycle and are more clearly defined globally (Paillard, 2001). Based upon similar research, oceanic productivity is expected to peak from glacial termination through the beginning of the following interglacial (Murray *et al.*, 2000b; Filippelli *et al.*, 2007) and the termination designation was used here for visualizing the temporal linkages between core records (Lisiecki and Raymo, 2005).

Results

The majority of this section focuses on P, Ba, and Ti results. Data for the elements Fe, Al, Ca, Zn, Sr, Mg, Mn, and S serve the purpose of adding to the sediment record and will be briefly mentioned.

Modern ocean productivity gradient

Using a SeaWiFS modern productivity map of the equatorial Pacific, a value was associated with each site (Fig 4); (Table 1). The map represents surface chlorophyll production from December 1999, a normal year versus an El Nino or La Nina year. As Table 1 shows, the sites closest to the equator (0^o-2^oN, S) have the highest productivity values. While further from the equator (7^oN), Site 845's productivity value is dissimilar to the other equatorial sites. Site 845 has a relatively low value which is characteristic of basins due to high export of non-nutritive terrigenous sediment.

Elemental averages

The mean of each element was calculated to represent an average concentration over the past 1Ma for each site (Table 2). Average elemental range values can be found in Table 3. Average concentrations for P, Ba, and Ti do not follow the productivity gradient; however, application of the P/Ti and Ba/Ti proxy clarifies this inconsistency. P and Ba concentration values are almost identical within Sites 849 (Table 4), PC72, and RR0603-03. In Sites 848 (Table 5), 853 (Table 6), PC114, and 845 (Table 7), P and Ba values widely differ. Ba concentration is nearly half that of P concentrations in Site 848, while the Ba value is double the P value in Site PC114. P, Ba, and Ti data for individual EEP samples can be found in Tables 4-7.

Ti represents the sample's overall terrigenous component and is expected to be more abundant in sites on the productivity gradient's lower end. This is exemplified by basin Site 845 containing the highest amount of Ti, 39µmol/g. Sites closest to the equator contain the least amount of Ti, approximately 1µmol/g. This is expected because, relative to basin areas, terrigenous export at the equator is less due to proximity to the continental shelf.

Proxy comparison

Site 849 has an average P/Ti ratio of 17.8 yet a lesser Ba/Ti ratio of 13.3 (Table 1). Site 848, slightly south of the equator has an average P/Ti ratio of 18.3 which is much higher than its Ba/Ti ratio, 8.4 (Table 1). For sites further north and/or west, their average P/Ti and Ba/Ti ratios decrease. The average P/Ti ratio for Site 853 (7^{o}N) is 3.2 with a similar average Ba/Ti ratio, 2.1 (Table 1). Site RR0603, while on the equator, is further west than Site 848 and 849, and has an average P/Ti ratio 3.6. In contrast to its P/Ti ratio, Site RR0603's Ba/Ti ratio is 17. This same pattern occurs in Site PC72 with an average P/Ti ratio of 4.6 and an average Ba/Ti ratio of 17. Further north and west, Site PC114 has an average P/Ti value of 1.1, which is slightly higher than Site 845 (0.9). The average Ba/Ti ratios between Site PC114 and Site 845 differ significantly, 0.7 and 8.5 respectively.

Glacial and interglacial productivity variations

In order to evaluate productivity variations over the past 1Ma, the applied export production proxies were plotted versus age (Figs 5, 6). Productivity is expected to be highest at the glacial peaks and terminations, indicated by the gray bars on the graph. Site 849 is not included on this graph due to insufficient number of samples.

Beyond quantitative analysis, applied proxy data in relation to an age model can be used to visually demonstrate how the ‘excess P’ or productivity varies over glacial time periods. Figure 5 shows P/Ti ratios for the last seven glacial terminations. The sites have been arranged to reflect high (top) to low (bottom) modern chlorophyll production. P/Ti ratios at site 845 (basin) had the lowest values (expected), while site 848, just 2 degrees north of the equator had the highest P/Ti values, 10-30 g/g. The second highest values were at RR0603 and PC72 which ranged between 1-12 g/g. These sites are located on the equator, which would be expected to have the highest ranges. The next two sites, 853 and PC114, range similar values of approximately 1-5 g/g. These values would be expected to be lowest, except the basin site, because they are located further away from the equator in the south direction.

Variations in each site’s export production are visually represented as ‘cycles’ (Figs 5, 6). In each site, cyclic patterns of high export production during glacial terminations are followed by a productivity decrease during the terminations end. The cyclic patterns are better visually represented in the high resolution sampled sites; however, patterns among the constrained points can still be observed in the lower resolution sites.

P vs. Ba relationship

Cross plot analysis of P and Ba values from the EEP sites was used to evaluate the relationship between these elements (Figs 7-10). Sigma Plot graphs determined Site 848’s r^2 value to be 0.42, and Site 845’s r^2 value to be 0.33 (Figs 7, 10). These values indicate no significant relationship between P and Ba concentrations. One possible explanation for Site 845’s low r^2 value may be the area’s high terrigenous input, indicated by the site's 1.6cm/kyr sedimentation rate. Because these values represent total P and Ba, one element could be one element could be more closely associated with terrigenous sedimentation than the other. If this were the case, both elements would not demonstrate a strong relationship. On the other hand, sites 849 and 853 demonstrate much higher correlation coefficients, 0.6 and 0.7, respectively (Figs 8, 9). With considerably less terrigenious input than site 845, sites 849 and 853 are more than likely demonstrating a strong relationship due to the majority of total P and Ba being biogenically associated. The P and Ba relationship variations among sites demonstrate that analysis of total biogenic element values alone do not provide accurate export production measurements.

Geochemistry

All elemental data (Mn, Zn, S, Sr, Fe, Al, Mg, and Ca) for each site can be found in Tables 8-15. Elements such as Fe, Al, Mg and Sr have been used in relation to other productivity proxies, but are provided here mainly to complete the sediment record.

Metals Fe, Al, and Ti from site 845 have higher average concentrations relative to the high productivity sites. Because site 845 is a low productivity basin site, these terrigenious related metals are not diluted significantly by biogenic matter. Fe, Al, and Ti have average concentration values of 634, 1203, and 39μmol/g, respectively (Table 1). The next highest average concentration is seen at site 853, which is located outside of the productivity transect. Average concentrations for sites RR0603 and site 848, in the core of equatorial productivity, are less than one fifth that of site 845. Al values reveal a similar trend; site 845 averages 1203μmol/g while RR0603 and 848 values are approximately one tenth of that. Ti follows this pattern as well, averaging 35μmol/g for site 845 but being significantly low at other sites.

Discussion

Proxy normalization

It is expected that at site 845, biogenically related elements like P and Ba, would be considerably lower than the higher productivity sites; however, this is not represented by the P and Ba concentration values independently. Site 845 averaged 35µmol/g of P and 30µmol/g of Ba (Table 7). Of all the sites only 853 had higher P and Ba concentration values than 845. When Ti, or Al, is used to normalize the biological (P or Ba) components, the ratio represents an estimate of the excess biogenic component. For this reason, direct surface productivity cannot be measured via P or Ba concentrations alone. The calculated 'excess P' is what is then used to represent export production over glacial and interglacial intervals. For example, Site 845 has a high average value, 38.9µmol/g of Ti which is expected due to its relatively high terrigenous accumulation (Table 7). Average values for P and Ba are 35 and 30µmol/g. When the P/Ti and Ba/Ti proxies are applied, export production is 0.92g/g and 0.77g/g, which is very low relative to the other sites (Table 7). However, these low P/Ti and Ba/Ti values are expected due to the site's high terrigenous input. In contrast, Sites 849 and 848, closest to the equator, had the highest P/Ti ratios in the transect, 17.8g/g and 18.3g/g, respectively (Table 1). Within each proxy, normalization with Ti proved to be a successful method of estimating export production at each site (Tables 1, 2).

Proxy comparison

When comparing P/Ti and Ba/Ti values to the modern productivity gradient, P/Ti demonstrated a stronger correlation than Ba/Ti (Table 1). Ba/Ti values occur in an erratic order, while the modern gradient and P/Ti values follow an increasing to decreasing order. One possible explanation for this is Ba is an indirect proxy for productivity while P is more direct application.

Glacial and interglacial productivity variations

Analysis of the four EEP site's P/Ti and Ba /Ti ratios revealed distinct productivity variations during glacial terminations and interglacial periods. The observed variations agree with a pattern of increased productivity during glacial periods and lower productivity during interglacial periods (Figs 5, 6). While the P/Ti ratio cyclic patterns from Leg 138 sites did not consistently mirror those patterns of the comparative sites, significant peaks during glacial terminations were still observed despite sample number constraints.

Conclusion

The SNH incorporates several biological, chemical, and environmental processes which form a detailed hypothesis explaining potential paleoproductivity drivers over past glacial cycles. This study's purpose served to contribute to the EEP's sediment record, analyze two applied export production proxies and their effectiveness in measuring productivity, and to demonstrate observed productivity variations in relation to similar research.

Although the core sites used in this study are limited to spatial extent, the nutrient proxies have global implications. The high productivity peaks during glacial periods observed in ODP sites 848, 849, and 853 provide more support than refutation of the SNH. Finding that the CEP and EEP sites demonstrate similar productivity estimates helps to close another knowledge gap between these two areas. Piecing together information from sediment records of other high productivity sites, like the Southern Ocean, are vital in understanding how the world's oceans react to extreme changes in climate overtime. The first step in understanding these reactions is clarifying the relationship between ocean productivity and climate change. Only when we understand how oceans and climate interacted in the past can reliable models of future responses to climate change be created.

Table 1. Average proxy ratios (g/g) for each site. Sites are arranged in the order of their modern ocean chlorophyll gradient value.

Site	**Lat.**	**Long.**	**P/Ti**	**Ba/Ti**	**Chlorophyll a (mg m^{-3})**
849	0^{o} N	110^{o} W	17.81	13.33	0.35
848	2^{o} S	110^{o} W	18.35	8.42	0.3
853	7^{o} N	109^{o} W	3.26	2.16	0.3
PC 72	0^{o} N	139^{o} W	4.6	17	0.275
RR0603	2^{o} N	117^{o} W	3.60	14	0.275
PC 114	4^{o} N	139^{o} W	1.1	8.5	0.175
845	9^{o} N	34^{o} W	0.93	0.77	N/A

Table 2. Average elemental concentration values for each site (µmol/g). Sites are arranged from highest (Site 849) to lowest (Site 845) chlorophyll a production.

Site	**Lat.**	**Long.**	**Ba**	**P**	**Zn**	**Mn**	**S**	**Ti**	**Sr**	**Fe**	**Al**	**Ca**	**Mg**
849	0° N	110° W	19.1	19.3	2.1	50	221	1.7	15.4	310	357	4453	204
848	2° S	110° W	9.2	19.1	1.9	15	198	1.1	15.5	94	95	6837	N/A
853	7° N	109° W	34.3	50	2.9	172	260	15.9	15.8	542	542	3953	300
PC 72	0° N	139° W	10	11	N/A	N/A	N/A	1.9	N/A	N/A	119	N/A	N/A
RR0603	2° N	117° W	14	14	1.2	54	135	4	10	84	123	4400	130
PC 114	4° N	139° W	15	7.1	N/A	N/A	N/A	5.6	N/A	N/A	265	N/A	N/A
845	9° N	34° W	29.8	35	8.2	35.8	249	38.9	3.2	634	1203	647	674

Table 3. Elemental ranges for each site (μmol/g). Sites are arranged from highest (Site 849) to lowest (Site 845) chlorophyll a production.

Site	**Coordinates**	**Ba**	**P**	**Zn**	**Mn**	**S**	**Ti**	**Sr**	**Fe**	**Al**	**Ca**
849	0° N; 139° W	11-29	11-24	1-3	12-123	109-313	0-3	9-18	47-585	81-758	3364-5008
848	2° S; 110° W	0.8-26	0.9-25	0.1-5	0.8-26	15-224	0.1-2	0.9-20	12-247	12-239	636-8234
853	4° N; 139° W	15-71	27-76	2-4	102-286	148-332	8-25	8-19	111-1334	111-1334	90-5418
RR0306	2° N; 117° W	5-38	5-33	0-4	12-459	80-349	0-8	3-14	11-329	32-579	3833-7129
PC 72	0° N; 110° W	3-35	2-31	N/A	N/A	N/A	0.3-7	N/A	N/A	26-461	N/A
PC 114	7° N; 109° W	3-48	2 - 19	N/A	N/A	N/A	0.7-19	N/A	N/A	45-826	N/A
845	9° N; 34° W	16-42	26-45	5-12	19-35	143-551	26-52	2-4	433-917	746-1548	191-1858

Table 4. Site 849 concentration values for elements P, Ba, and Ti (µmol/g) with standard deviation and percent error.

Sample ID	Depth (mcd)	Age (Ma)	P	std dev	% Error	Ba	std dev	% Error	Ti	std dev	% Error
849A.1.1.0	0.00	0.00	20.19	1.38	6.81	18.34	0.11	0.61	1.02	0.00	0.45
849A.1.1.27	0.27	0.01	18.16	2.33	12.81	16.65	0.24	1.41	0.62	0.01	2.32
849A.1.1.57	0.57	0.02	21.09	1.76	8.34	17.28	0.27	1.55	1.49	0.01	0.84
849A.1.1.87	0.87	0.03	22.24	2.80	12.57	14.14	0.36	2.53	1.20	0.04	3.08
849A.1.1.118	1.18	0.05	18.89	0.77	4.08	12.33	0.20	1.64	0.88	0.04	4.59
849A.1.2.2	1.52	0.05	52.04	1.68	3.23	6.90	0.09	1.36	1.06	0.01	0.92
849A.1.2.28	1.78	0.06	20.06	0.76	3.79	12.41	0.38	3.10	0.81	0.03	4.32
849A.1.2.60	2.10	0.07	24.52	1.05	4.28	24.86	0.30	1.20	2.63	0.04	1.69
849A.1.2.88	2.38	0.07	24.84	1.27	5.13	27.98	0.59	2.12	2.85	0.01	0.40
849A.1.2.118	2.68	0.08	20.00	2.22	11.08	26.04	0.42	1.60	2.32	0.04	1.57
849B.1.3.10	3.10	0.10	20.25	0.14	0.71	23.54	0.23	0.99	1.77	0.05	2.96
849B.1.3.38	3.38	0.11	22.77	0.42	1.83	29.43	0.30	1.02	2.29	0.01	0.27
849B.1.3.65	3.65	0.12	23.22	1.74	7.48	22.42	0.08	0.38	1.20	0.02	1.33
849B.1.3.86	3.86	0.12	21.47	0.59	2.76	19.34	0.34	1.77	1.50	0.03	2.31
849B.1.3.112	4.12	0.13	18.70	0.53	2.83	16.21	0.15	0.95	1.74	0.04	2.23
849B.1.3.142	4.42	0.14	16.66	1.90	11.43	12.88	0.12	0.93	1.10	0.01	0.66

Table 5. Site 848 concentration values for elements P, Ba, and Ti (µmol/g) with standard deviation and percent error.

Sample ID	Depth (mcd)	Age (Ma)	P	std dev	% error	Ba	std dev	% error	Ti	std dev	% error
848B.1.1.3	0.23	0.01	21.34	0.94	4.42	10.31	0.30	2.92	2.03	0.02	1.13
848B.1.1.33	0.53	0.03	22.93	1.05	4.59	12.53	0.24	1.89	1.37	0.03	2.07
848B.1.1.63	0.83	0.05	18.82	0.76	4.05	10.11	0.17	1.65	1.26	0.03	2.75
848B.1.1.90	1.10	0.07	21.60	0.67	3.11	15.26	0.11	0.75	1.51	0.05	3.57
848B.1.1.120	1.40	0.08	25.94	1.06	4.09	25.34	0.55	2.16	2.22	0.07	3.20
848B.1.1.146	1.66	0.10	19.96	1.70	8.53	19.85	0.09	0.44	1.51	0.03	2.01
848B.1.2.0	1.70	0.11	2.08	0.23	11.10	1.66	0.02	1.30	0.14	0.00	1.24
848B.1.2.30	2.00	0.14	20.70	0.50	2.42	12.57	0.07	0.54	1.37	0.03	2.53
848B.1.2.55	2.25	0.15	21.30	1.82	8.54	10.33	0.27	2.58	1.46	0.06	3.82
848B.1.cc.0	2.28	0.16	23.69	0.20	0.85	12.54	0.48	3.86	1.53	0.06	3.93
848B.2.1.0	5.00	0.36	18.28	1.17	6.38	8.69	0.10	1.20	1.11	0.05	4.53
848B.2.1.30	5.30	0.38	20.82	0.75	3.61	10.31	0.23	2.22	1.21	0.02	1.91
848B.2.1.56	5.56	0.40	25.43	1.32	5.20	11.86	0.18	1.52	1.32	0.04	2.98
848B.2.1.90	5.59	0.41	19.79	0.62	3.13	7.14	0.07	0.97	0.96	0.01	1.19
848B.2.1.122	6.22	0.43	19.89	1.06	5.35	5.38	0.16	2.90	0.88	0.02	2.46
848B.2.1.145	6.45	0.43	18.23	0.74	4.07	5.30	0.02	0.45	0.79	0.01	1.73
848B.2.2.0	6.50	0.44	20.20	1.68	8.32	5.20	0.07	1.41	0.85	0.02	2.65
848B.2.2.31	6.81	0.46	19.18	0.80	4.18	6.06	0.11	1.86	0.83	0.02	2.62
848B.2.2.56	7.06	0.47	21.61	1.25	5.78	12.54	0.07	0.60	1.36	0.06	4.50
848B.2.2.94	7.44	0.49	19.08	0.31	1.64	8.57	0.17	2.03	1.11	0.01	0.61
848B.2.2.122	7.72	0.52	17.64	1.70	9.63	6.90	0.09	1.37	0.98	0.01	1.20
848B.2.2.145	7.95	0.53	17.73	0.38	2.17	7.10	0.01	0.15	0.91	0.04	4.52
848B.2.3.0	8.00	0.54	18.08	0.45	2.50	6.44	0.09	1.34	0.87	0.00	0.50
848B.2.3.31	8.31	0.55	19.20	1.65	8.61	6.52	0.10	1.54	0.89	0.04	3.94

Table 5 Cont. Site 848 concentration values for elements P, Ba, and Ti (μmol/g) with standard deviation and percent error.

Sample ID	Depth (mcd)	Age (Ma)	P	std dev	% error	Ba	std dev	% error	Ti	std dev	% error
848B.2.3.60	8.60	0.56	21.10	0.56	2.65	14.05	0.24	1.71	1.35	0.05	3.53
848B.2.3.90	8.90	0.57	21.31	1.55	7.27	10.68	0.21	1.96	1.13	0.01	0.88
848B.2.3.123	9.23	0.60	20.62	0.81	3.94	13.48	0.24	1.75	1.29	0.02	1.31
848B.2.3.145	9.45	0.62	20.63	0.50	2.43	9.72	0.14	1.46	1.04	0.01	0.76
848B.2.4.0	9.50	0.62	17.53	0.95	5.44	8.09	0.12	1.52	0.96	0.02	2.28
848B.2.4.32	9.82	0.64	18.04	0.38	2.12	5.79	0.06	1.11	0.83	0.02	2.62
848B.2.4.66	10.16	0.65	17.97	1.22	6.79	4.67	0.03	0.59	0.76	0.02	2.84
848B.2.4.90	10.40	0.67	20.19	1.07	5.31	8.73	0.14	1.59	1.08	0.02	2.09
848B.2.4.123	10.73	0.67	24.46	1.09	4.44	15.33	0.56	3.63	1.46	0.03	2.34
848B.2.4.145	10.95	0.69	19.29	0.58	3.01	7.37	0.08	1.08	0.90	0.02	2.55
848B.2.5.0	11.00	0.70	18.15	0.47	2.59	6.99	0.11	1.59	0.88	0.01	0.88
848B.2.5.31	11.31	0.71	20.33	0.58	2.83	11.07	0.14	1.30	1.22	0.01	1.22
848B.2.5.60	11.60	0.73	17.62	0.98	5.54	6.38	0.09	1.39	0.86	0.02	2.12
848B.2.5.90	11.90	0.75	19.46	0.94	4.84	7.65	0.08	1.05	1.06	0.02	2.11
848B.2.5.122	12.22	0.78	21.80	1.46	6.68	11.14	0.20	1.79	1.28	0.06	4.56
848B.2.5.146	12.46	0.78	21.22	0.93	4.40	8.15	0.18	2.25	0.94	0.02	1.94
848B.2.6.0	12.50	0.80	19.75	0.48	2.42	8.40	0.13	1.54	0.92	0.01	1.14
848B.2.6.31	12.81	0.81	18.10	1.72	9.49	6.28	0.14	2.29	0.95	0.02	2.15
848B.2.6.56	13.40	0.82	13.59	1.14	8.39	6.18	0.08	1.28	0.81	0.00	0.48
848B.2.6.90	13.72	0.84	19.06	0.42	2.19	15.12	0.24	1.61	1.35	0.02	1.66
848B.2.6.122	13.72	0.85	24.28	1.56	6.44	19.13	0.24	1.28	1.58	0.01	0.47
848B.2.7.0	14.00	0.87	23.51	0.58	2.46	10.16	0.17	1.64	1.32	0.03	2.61
848B.2.7.32	14.32	0.88	21.06	1.04	4.95	8.70	0.13	1.44	1.01	0.01	1.37
848B.2.7.56	14.56	0.89	21.76	0.68	3.15	5.77	0.19	3.24	0.80	0.03	3.42

Table 5 Cont. Site 848 concentration values for elements P, Ba, and Ti (μmol/g) with standard deviation and percent error.

Sample ID	Depth (mcd)	Age (Ma)	P	std dev	% error	Ba	std dev	% error	Ti	std dev	% error
848B.2.cc.0	14.85	0.90	19.69	0.43	2.17	6.92	0.21	3.00	0.98	0.02	2.22
848B.3.1.0	15.65	0.95	0.97	0.03	3.35	0.99	0.00	0.29	2.02	0.10	5.03
848B.3.1.30	15.95	0.99	1.08	0.04	3.56	0.90	0.01	0.94	2.22	0.03	1.13
848B.3.1.66	16.31	1.01	1.12	0.06	4.97	0.95	0.02	2.26	2.17	0.07	3.34
848B.3.1.90	16.55	1.03	0.98	0.06	5.96	0.57	0.01	2.52	1.98	0.05	2.47

Table 6. Site 853 concentration values for elements P, Ba, and Ti (µmol/g) with standard deviation and percent error.

Sample ID	Depth (mcd)	Age (Ma)	P	std dev	% error	Ba	std dev	% error	Ti	std dev
853B.1.1.20	0.2	0	38.26	0.51	1.33	24.19	0.41	1.71	11.12	0.12
853B.1.1.35	0.35	0.043	59.68	1.05	1.75	36.06	1.16	3.22	21.65	0.43
853B.1.1.50	0.5	0.08	40.82	2.83	6.94	22.84	0.40	1.75	11.76	0.17
853B.1.1.66	0.66	0.12	67.70	1.60	2.37	53.72	1.01	1.89	25.19	0.35
853B.1.1.83	0.83	0.17	61.09	1.40	2.30	47.67	0.83	1.74	22.56	0.41
853B.1.1.97	0.97	0.21	49.22	0.72	1.46	38.44	0.62	1.60	22.01	0.26
853C.1.1.0	1.1	0.23	52.55	1.56	2.96	35.77	0.91	2.55	17.93	0.27
853B.1.1.112	1.12	0.2515	44.90	0.41	0.91	25.74	0.37	1.43	14.27	0.15
853C.1.1.15	1.25	0.273	53.74	0.49	0.92	41.10	0.65	1.58	19.61	0.29
853B.1.1.127	1.27	0.2945	52.32	0.50	0.95	35.69	0.36	1.01	17.06	0.07
853C.1.1.30	1.4	0.316	51.10	1.59	3.12	35.30	0.50	1.42	18.52	0.19
853B.1.1.142	1.42	0.3375	43.16	0.79	1.84	22.94	0.24	1.04	10.69	0.14
853C.1.1.45	1.55	0.359	48.58	0.89	1.83	35.89	0.51	1.43	16.85	0.12
853B.1.2.0	1.5	0.3805	52.25	0.61	1.17	35.95	0.17	0.49	14.89	0.14
853B.1.2.20	1.7	0.43	48.46	2.18	4.49	23.82	0.33	1.37	10.81	0.18
853C.1.1.60	1.7	0.4582	50.55	0.63	1.24	40.24	0.48	1.18	20.33	0.24
853C.1.1.73	1.83	0.4864	41.66	1.45	3.49	28.42	0.52	1.82	15.09	0.19
853B.1.2.36	1.86	0.5146	61.63	0.73	1.19	35.93	0.85	2.37	15.12	0.27
853B.1.2.50	2	0.5562	60.92	0.62	1.01	35.78	0.38	1.06	16.95	0.44
853C.1.1.90	2	0.577	35.42	0.53	1.51	24.57	0.43	1.76	9.64	0.07
853B.1.2.65	2.15	0.5978	40.97	0.11	0.26	24.00	0.33	1.37	12.78	0.15
853C.1.1.105	2.15	0.6186	55.79	0.81	1.45	40.70	0.39	0.95	16.59	0.07
853B.1.2.80	2.3	0.6394	38.45	1.18	3.08	30.04	0.20	0.66	13.86	0.06
853C.1.1.120	2.3	0.6602	27.15	1.23	4.55	15.74	0.23	1.44	8.38	0.13
853B.1.2.95	2.45	0.681	52.61	1.05	2.00	34.52	0.56	1.63	15.96	0.23
853C.1.1.135	2.45	0.693375	43.96	1.64	3.73	21.52	0.36	1.69	12.43	0.15

Table 6 Cont. Site 853 concentration values for elements P, Ba, and Ti (μmol/g) with standard deviation and percent error.

Sample ID	Depth (mcd)	Age (Ma)	P	std dev	% error	Ba	std dev	% error	Ti	std dev
853B.1.2.111	2.61	0.70575	46.50	1.74	3.74	23.47	0.64	2.71	12.80	0.21
853B.1.2.125	2.75	0.7305	51.35	1.00	1.95	34.06	0.51	1.51	16.12	0.27
853B.1.2.140	2.9	0.75525	60.25	0.28	0.46	40.68	0.86	2.11	18.11	0.22
853B.1.3.1	3.01	0.81	59.13	1.27	2.14	40.19	0.89	2.21	16.47	0.28
853B.1.3.17	3.17	0.84	48.97	0.80	1.63	22.04	0.35	1.59	12.66	0.35
853B.1.3.30	3.3	0.87	55.28	2.49	4.50	40.47	0.36	0.88	15.88	0.21
853B.1.3.47	3.47	0.9	76.65	0.63	0.83	71.03	1.14	1.60	25.63	0.31
853B.1.3.58	3.58	0.93	62.04	1.03	1.66	62.23	0.75	1.21	23.56	0.33
853B.1.3.78	3.78	0.96	50.81	1.03	2.03	43.25	1.02	2.35	15.63	0.14
853B.1.3.93	3.93	1.0166	47.09	1.42	3.01	27.45	0.42	1.54	11.03	0.17
853B.1.3.107	4.07	1.0432	41.53	1.43	3.45	31.36	0.28	0.89	12.08	0.05

Table 7. Site 845 concentration values for elements P, Ba, and Ti (µmol/g) with standard deviation and percent error.

Sample ID	Depth (mcd)	Age (Ma)	P	std dev	% error	Ba	std dev	% error	Ti	std dev	% error
845A.1.1.140	1.40	0.02	34.24	0.71	2.07	31.58	0.70	2.21	41.60	0.19	0.45
845A.1.2.20	1.70	0.03	35.36	0.84	2.39	27.86	0.24	0.85	36.97	0.16	0.42
845A.1.2.58	2.08	0.05	39.06	1.35	3.45	27.31	0.33	1.22	36.43	0.22	0.60
845A.1.2.99	2.49	0.06	35.47	0.72	2.02	27.61	0.28	1.02	34.62	0.55	1.58
845A.1.2.140	2.90	0.08	34.06	1.41	4.15	23.27	0.19	0.83	32.25	0.30	0.92
845A.1.3.20	3.20	0.09	38.88	0.76	1.96	33.39	0.28	0.84	38.02	0.60	1.57
845A.1.3.99	4.40	0.12	38.92	0.51	1.32	26.01	0.18	0.71	49.68	0.76	1.52
845A.1.3.140	4.70	0.14	44.66	0.95	2.13	31.47	0.36	1.15	48.72	0.26	0.53
845A.1.4.20	5.07	0.15	36.84	0.26	0.71	27.92	0.40	1.42	42.15	0.42	0.99
845A.1.4.57	5.52	0.17	38.74	0.62	1.59	30.30	0.22	0.74	36.04	0.14	0.38
845A.1.4.102	5.91	0.18	31.05	0.99	3.20	21.90	0.26	1.20	27.78	0.35	1.25
845A.1.4.141	6.18	0.20	39.99	1.37	3.42	33.79	0.53	1.57	37.42	0.26	0.70
845A.1.5.18	6.58	0.21	28.00	1.05	3.76	29.33	1.26	4.28	26.20	0.21	0.80
845A.1.5.58	7.03	0.23	37.63	1.22	3.25	31.16	0.39	1.25	40.03	0.46	1.16
845A.1.5.103	7.41	0.24	44.68	1.28	2.87	33.15	0.26	0.78	44.76	0.14	0.32
845A.1.5.141	8.69	0.26	44.58	0.08	0.19	36.48	0.28	0.76	46.54	0.21	0.46
845A.2.1.21	9.06	0.28	45.02	0.96	2.12	32.80	0.37	1.12	36.30	0.51	1.39
845A.2.1.58	9.47	0.29	33.45	1.67	5.00	25.84	0.16	0.62	28.64	0.14	0.51
845A.2.1.99	9.88	0.31	37.66	1.26	3.35	21.30	0.12	0.57	30.90	0.58	1.87
845A.2.1.140	10.06	0.33	35.09	0.99	2.81	17.59	0.16	0.91	40.50	0.76	1.87
845A.2.2.8	10.49	0.34	35.96	0.34	0.94	16.25	0.05	0.29	49.15	0.53	1.07
845A.2.2.51	10.86	0.36	37.91	0.19	0.51	30.53	0.21	0.68	37.33	0.11	0.28
845A.2.2.88	11.26	0.37	40.17	0.86	2.15	32.02	0.69	2.14	39.10	0.52	1.33

Table 7 Cont. Site 845 concentration values for elements P, Ba, and Ti (μmol/g) with standard deviation and percent error.

Sample ID	Depth (mcd)	Age (Ma)	P	std dev	% error	Ba	std dev	% error	Ti	std dev	% error
845A.3.2.130	20.76	0.82	30.05	1.00	3.34	21.87	0.28	1.26	33.92	0.45	1.34
845A.3.3.10	21.06	0.84	35.09	0.97	2.77	26.52	0.13	0.48	39.78	0.56	1.40
845A.3.3.50	21.46	0.86	35.85	0.78	2.18	36.21	0.31	0.86	42.74	0.40	0.95
845A.3.3.90	21.86	0.87	31.69	0.26	0.83	34.27	0.29	0.85	39.27	0.21	0.55
845A.3.3.130	22.26	0.89	35.44	0.64	1.79	34.31	0.56	1.63	39.84	0.24	0.59
845A.3.4.10	22.26	0.91	33.56	1.04	3.10	28.55	0.34	1.17	39.62	0.60	1.52
845A.3.4.48	22.94	0.93	35.00	0.43	1.24	33.85	0.19	0.57	40.17	0.38	0.94
845A.3.4.90	23.36	0.95	33.92	1.21	3.57	38.74	0.38	0.99	42.57	0.18	0.42
845A.3.4.132	23.78	0.96	35.13	0.21	0.59	36.10	0.43	1.19	43.96	0.15	0.34
845A.3.5.10	24.06	0.98	31.64	1.74	5.51	36.47	0.38	1.04	39.09	0.13	0.33
845A.3.5.48	24.44	1.00	30.46	0.98	3.22	35.38	0.61	1.73	36.10	0.37	1.02

Table 8. Site 849 concentration values for elements Mn, Zn, S, and Sr (μmol/g) with standard deviation and percent error.

Sample ID	Mn	std dev	% error	Zn	std dev	% error	S	std dev	% error	Sr	std dev	% error
849A.1.1.0	43.89	0.24	0.54	3.76	0.07	1.98	241.10	3.34	1.39	18.31	0.30	1.61
849A.1.1.27	46.96	0.84	1.79	1.79	0.03	1.56	245.85	9.16	3.72	15.87	0.47	2.93
849A.1.1.57	45.36	0.83	1.82	1.61	0.04	2.29	226.75	5.81	2.56	17.60	0.38	2.17
849A.1.1.87	12.82	0.18	1.38	1.16	0.03	2.52	109.14	10.67	9.78	9.58	0.12	1.27
849A.1.1.118	26.17	0.20	0.76	1.63	0.05	2.96	228.07	11.36	4.98	17.61	0.43	2.45
849A.1.2.2	44.72	0.43	0.95	1.46	0.06	4.26	179.04	3.10	1.73	16.00	0.38	2.35
849A.1.2.28	22.74	0.06	0.27	1.82	0.07	3.57	221.54	6.74	3.04	17.80	0.37	2.11
849A.1.2.60	63.97	0.95	1.49	1.65	0.05	2.96	223.08	10.10	4.53	15.32	0.22	1.46
849A.1.2.88	39.88	0.45	1.14	1.81	0.01	0.42	270.92	19.89	7.34	17.23	0.40	2.31
849A.1.2.118	123.80	2.85	2.30	2.05	0.10	4.73	313.52	8.38	2.67	17.56	0.53	3.03
849B.1.3.10	18.82	0.49	2.63	1.68	0.10	5.67	244.05	4.45	1.83	10.24	0.31	3.06
849B.1.3.38	71.95	0.71	0.99	1.94	0.06	3.06	204.04	4.43	2.17	13.45	0.31	2.29
849B.1.3.65	50.34	0.50	1.00	3.04	0.04	1.41	240.46	10.32	4.29	16.30	0.28	1.70
849B.1.3.86	101.06	1.04	1.03	3.05	0.12	3.83	166.61	3.70	2.22	11.50	0.18	1.54
849B.1.3.112	43.10	0.38	0.89	2.95	0.03	0.94	230.27	8.98	3.90	17.14	0.25	1.44
849B.1.3.142	46.28	0.46	1.00	2.77	0.05	1.66	191.76	8.63	4.50	15.00	0.35	2.32

Table 9. Site 848 concentration values for elements Mn, Zn, S, and Sr (μmol/g) with standard deviation and percent error.

Sample ID	Mn	std dev	% error	Zn	std dev	% error	S	std dev	% error	Sr	std dev	% error
848B.1.1.3	24.00	0.30	1.23	1.89	0.01	0.54	201.56	8.30	4.12	12.59	0.15	1.22
848B.1.1.33	124.18	1.69	1.36	2.35	0.01	0.52	214.83	6.69	3.11	14.06	0.22	1.56
848B.1.1.63	8.96	0.08	0.86	2.11	0.02	0.97	194.16	4.43	2.28	12.10	0.19	1.59
848B.1.1.90	14.27	0.10	0.69	2.04	0.01	0.55	206.10	13.90	6.74	11.00	0.39	3.59
848B.1.1.120	25.58	0.24	0.93	2.47	0.03	1.23	231.62	7.19	3.10	8.83	0.19	2.10
848B.1.1.146	16.28	0.14	0.85	2.38	0.02	0.90	209.14	4.47	2.14	8.08	0.11	1.42
848B.1.2.0	2.20	0.02	0.89	0.22	0.00	1.63	21.22	1.02	4.79	0.96	0.01	0.55
848B.1.2.30	16.22	0.22	1.34	2.14	0.03	1.58	221.92	2.74	1.23	12.24	0.24	1.92
848B.1.2.55	8.87	0.23	2.58	2.77	0.05	1.69	234.09	8.63	3.69	13.70	0.18	1.34
848B.1.cc.0	9.74	0.21	2.19	2.29	0.01	0.60	246.67	16.11	6.53	12.35	0.18	1.46
848B.2.1.0	9.39	0.19	2.05	2.09	0.02	1.17	220.34	6.44	2.92	14.93	0.12	0.82
848B.2.1.30	11.57	0.22	1.87	2.36	0.04	1.75	246.94	9.29	3.76	18.08	0.36	1.98
848B.2.1.56	11.77	0.19	1.58	2.03	0.01	0.44	220.79	19.55	8.85	18.32	0.23	1.27
848B.2.1.90	14.38	0.18	1.28	1.72	0.01	0.57	217.68	16.21	7.45	19.54	0.13	0.64
848B.2.1.122	13.41	0.30	2.26	1.70	0.02	1.13	229.71	9.97	4.34	15.35	0.09	0.58
848B.2.1.145	14.34	0.13	0.93	1.63	0.01	0.51	214.31	4.05	1.89	16.88	0.10	0.59
848B.2.2.0	16.01	0.25	1.54	1.82	0.03	1.72	206.09	15.85	7.69	18.57	0.11	0.59
848B.2.2.31	13.92	0.18	1.29	1.94	0.03	1.38	182.98	16.60	9.07	18.37	0.33	1.82
848B.2.2.56	14.92	0.14	0.95	1.84	0.02	1.00	218.74	5.72	2.61	19.94	0.18	0.89
848B.2.2.94	13.78	0.16	1.14	1.73	0.02	1.42	204.74	6.21	3.03	19.18	0.11	0.58
848B.2.2.122	12.91	0.21	1.62	1.71	0.01	0.74	199.59	8.55	4.28	14.93	0.07	0.44
848B.2.2.145	14.85	0.06	0.40	1.70	0.01	0.76	185.19	9.39	5.07	15.42	0.31	2.02
848B.2.3.0	12.59	0.14	1.13	1.69	0.02	1.19	200.86	14.42	7.18	12.68	0.13	0.99
848B.2.3.31	12.11	0.24	1.96	1.77	0.03	1.60	216.85	5.06	2.33	14.49	0.16	1.07

Table 9 Cont. Site 848 concentration values for elements Mn, Zn, S, and Sr (µmol/g) with standard deviation and percent error.

Sample ID	Mn	std dev	% error	Zn	std dev	% error	S	std dev	% error	Sr	std dev	% error
848B.2.3.60	13.71	0.21	1.50	1.96	0.00	0.10	221.27	9.86	4.46	16.99	0.32	1.87
848B.2.3.90	13.98	0.19	1.33	1.78	0.01	0.81	197.98	5.74	2.90	16.74	0.21	1.28
848B.2.3.123	12.86	0.04	0.29	1.92	0.01	0.26	210.89	10.38	4.92	13.26	0.18	1.34
848B.2.3.145	14.94	0.12	0.80	1.85	0.00	0.13	196.69	2.98	1.52	15.43	0.29	1.87
848B.2.4.0	13.69	0.18	1.34	1.81	0.00	0.24	188.49	18.67	9.91	12.05	0.10	0.83
848B.2.4.32	13.71	0.16	1.19	1.78	0.04	2.22	233.82	7.34	3.14	14.72	0.17	1.15
848B.2.4.66	13.37	0.40	2.97	1.71	0.04	2.36	226.07	2.83	1.25	15.27	0.11	0.71
848B.2.4.90	14.73	0.05	0.36	1.83	0.04	2.07	186.96	9.87	5.28	12.68	0.26	2.07
848B.2.4.123	12.21	0.14	1.15	5.12	0.11	2.19	246.34	13.33	5.41	13.75	0.15	1.07
848B.2.4.145	13.55	0.15	1.14	1.79	0.01	0.52	184.84	17.87	9.67	12.20	0.26	2.17
848B.2.5.0	14.08	0.24	1.70	1.73	0.02	1.20	227.35	9.80	4.31	12.93	0.29	2.22
848B.2.5.31	13.85	0.11	0.77	1.92	0.00	0.20	219.42	13.99	6.38	16.00	0.28	1.77
848B.2.5.60	13.05	0.17	1.28	1.69	0.01	0.63	206.79	4.72	2.28	14.70	0.04	0.30
848B.2.5.90	13.62	0.09	0.65	2.27	0.03	1.29	197.07	7.29	3.70	14.92	0.04	0.27
848B.2.5.122	12.01	0.23	1.89	2.03	0.03	1.44	182.87	11.08	6.06	61.83	25.28	40.89
848B.2.5.146	15.63	0.22	1.42	1.80	0.01	0.79	220.01	17.75	8.07	16.57	0.26	1.59
848B.2.6.0	17.35	0.23	1.33	1.79	0.01	0.78	206.61	9.52	4.61	17.71	0.17	0.98
848B.2.6.31	13.45	0.26	1.93	2.23	0.01	0.47	201.67	2.60	1.29	15.02	0.12	0.77
848B.2.6.56	8.86	0.05	0.59	1.61	0.02	0.97	101.33	9.16	9.04	14.42	0.24	1.65
848B.2.6.90	14.10	0.09	0.62	1.94	0.01	0.59	198.39	5.06	2.55	15.69	0.13	0.82
848B.2.6.122	15.42	0.01	0.06	2.00	0.00	0.03	212.29	4.57	2.15	14.27	0.25	1.73
848B.2.7.0	18.72	0.23	1.25	1.96	0.01	0.60	223.68	10.66	4.77	13.01	0.16	1.20
848B.2.7.32	13.84	0.13	0.95	2.70	0.02	0.77	202.19	13.98	6.91	15.22	0.08	0.53
848B.2.7.56	15.87	0.42	2.64	1.76	0.02	1.34	203.59	4.66	2.29	15.20	0.16	1.06

Table 9 Cont. Site 848 concentration values for elements Mn, Zn, S, and Sr (µmol/g) with standard deviation and percent error.

Sample ID	Mn	std dev	% error	Zn	std dev	% error	S	std dev	% error	Sr	std dev	% error
848B.2.cc.0	17.39	0.33	1.91	1.84	0.01	0.55	214.23	8.99	4.20	15.13	0.20	1.30
848B.3.1.0	0.82	0.02	2.12	0.14	0.00	2.47	15.49	0.71	4.56	1.30	0.00	0.34
848B.3.1.30	0.82	0.00	0.44	0.07	0.00	1.64	16.80	0.53	3.18	0.91	0.01	1.42
848B.3.1.66	0.86	0.01	1.09	0.07	0.00	1.76	17.87	0.40	2.21	1.35	0.01	0.55
848B.3.1.90	1.12	0.01	1.05	0.06	0.00	2.98	16.96	0.40	2.36	1.23	0.01	1.08

Table 10. Site 853 concentration values for elements Mn, Zn, S, and Sr (µmol/g) with standard deviation and percent error.

Sample ID	Mn	std dev	% error	Zn	std dev	% error	S	std dev	% error	Sr	std dev	% error
853B.1.1.20	120.93	0.49	0.40	2.42	0.06	2.63	245.42	8.51	3.47	17.87	0.33	1.86
853B.1.1.35	212.59	4.67	2.20	3.77	0.06	1.57	323.58	4.88	1.51	15.25	0.43	2.83
853B.1.1.50	114.73	2.34	2.04	2.59	0.11	4.10	231.87	1.40	0.60	12.45	0.27	2.15
853B.1.1.66	191.93	1.76	0.92	3.56	0.05	1.33	310.09	17.19	5.55	16.12	0.39	2.40
853B.1.1.83	210.38	4.06	1.93	3.47	0.04	1.18	307.37	9.21	3.00	14.00	0.22	1.57
853B.1.1.97	120.93	1.79	1.48	3.47	0.07	2.15	304.84	15.20	4.99	16.88	0.38	2.25
853C.1.1.0	147.13	2.01	1.37	4.12	0.05	1.32	302.60	16.35	5.40	16.09	0.44	2.72
853B.1.1.112	128.93	1.56	1.21	2.61	0.03	1.32	236.34	6.32	2.67	15.93	0.27	1.67
853C.1.1.15	178.98	2.19	1.22	3.47	0.12	3.53	294.61	11.46	3.89	17.27	0.33	1.91
853B.1.1.127	179.46	1.51	0.84	3.09	0.05	1.62	224.32	1.83	0.82	16.19	0.18	1.09
853C.1.1.30	173.06	1.82	1.05	3.26	0.06	1.79	264.68	3.73	1.41	17.06	0.46	2.69
853B.1.1.142	158.49	0.23	0.14	2.72	0.05	2.02	213.42	2.85	1.33	16.06	0.27	1.69
853C.1.1.45	148.78	2.42	1.63	3.12	0.07	2.36	270.02	8.59	3.18	15.99	0.35	2.20
853B.1.2.0	164.76	1.90	1.16	3.03	0.06	1.90	261.09	13.28	5.09	17.85	0.26	1.46
853B.1.2.20	168.13	2.38	1.42	2.56	0.04	1.47	256.52	9.16	3.57	15.74	0.31	1.99
853C.1.1.60	177.11	2.55	1.44	3.13	0.06	1.89	250.47	5.41	2.16	16.80	0.25	1.51
853C.1.1.73	129.78	1.71	1.32	2.70	0.07	2.58	240.11	13.86	5.77	15.98	0.34	2.12
853B.1.2.36	213.66	2.68	1.25	3.06	0.10	3.15	316.07	4.30	1.36	18.64	0.31	1.69
853B.1.2.50	228.29	6.41	2.81	3.26	0.03	1.04	298.24	2.55	0.86	12.23	0.32	2.66
853C.1.1.90	117.22	1.26	1.08	2.50	0.09	3.64	194.15	10.12	5.21	11.69	0.29	2.52
853B.1.2.65	166.70	1.40	0.84	2.50	0.10	3.98	261.42	10.19	3.90	18.00	0.39	2.15
853C.1.1.105	189.30	3.08	1.63	3.04	0.07	2.38	254.03	14.91	5.87	15.82	0.24	1.51
853B.1.2.80	123.85	0.49	0.39	2.16	0.07	3.14	202.35	5.86	2.90	15.71	0.22	1.38
853C.1.1.120	102.50	1.41	1.38	2.02	0.08	4.18	148.19	2.72	1.83	8.83	0.17	1.92
853B.1.2.95	193.17	1.74	0.90	2.92	0.03	0.86	254.46	15.41	6.06	14.65	0.27	1.86
853C.1.1.135	221.57	4.31	1.94	3.18	0.07	2.21	308.99	3.76	1.22	19.55	0.57	2.91

Table 10 Cont. Site 853 concentration values for elements Mn, Zn, S, and Sr (µmol/g) with standard deviation and percent error.

Sample ID	Mn	std dev	% error	Zn	std dev	% error	S	std dev	% error	Sr	std dev	% error
853B.1.2.111	194.14	1.44	0.74	2.63	0.04	1.71	294.72	2.20	0.75	19.65	0.47	2.38
853B.1.2.125	194.35	2.40	1.23	2.92	0.03	1.00	241.39	16.41	6.80	14.56	0.31	2.16
853B.1.2.140	239.24	4.15	1.73	3.16	0.08	2.41	283.43	5.13	1.81	16.01	0.41	2.59
853B.1.3.1	165.95	2.57	1.55	3.30	0.03	0.95	284.98	9.26	3.25	14.97	0.48	3.19
853B.1.3.17	179.63	2.11	1.17	2.41	0.06	2.65	287.11	10.63	3.70	18.68	0.46	2.46
853B.1.3.30	210.67	3.39	1.61	2.88	0.02	0.56	259.36	10.71	4.13	14.80	0.28	1.91
853B.1.3.47	264.88	3.46	1.30	3.95	0.09	2.38	332.30	14.44	4.34	16.66	0.28	1.69
853B.1.3.58	286.60	2.00	0.70	3.57	0.10	2.78	274.48	10.97	4.00	16.30	0.15	0.89
853B.1.3.78	149.14	1.11	0.75	2.80	0.07	2.43	238.99	18.41	7.71	15.15	0.29	1.91
853B.1.3.93	148.69	2.36	1.59	2.53	0.05	2.13	242.72	9.85	4.06	16.25	0.48	2.96
853B.1.3.107	122.74	0.93	0.75	3.12	0.05	1.65	220.42	15.55	7.05	14.60	0.35	2.38

Table 11. Site 845 concentration values for elements Mn, Zn, S, and Sr (µmol/g) with standard deviation and percent error.

Sample ID	Mn	std dev	% error	Zn	std dev	% error	S	std dev	% error	Sr	std dev	% error
845A.1.1.140	38.69	0.14	0.36	11.58	0.08	0.69	220.96	12.11	5.48	3.03	1.90	0.72
845A.1.2.20	43.60	0.38	0.88	10.93	0.10	0.87	291.23	6.29	2.16	2.91	1.30	0.51
845A.1.2.58	35.58	1.12	3.15	10.50	0.05	0.44	294.85	14.82	5.03	2.81	0.78	0.32
845A.1.2.99	32.92	0.35	1.06	6.45	0.09	1.32	237.94	13.15	5.53	2.95	1.54	0.60
845A.1.2.140	32.13	0.33	1.02	6.02	0.05	0.84	203.39	14.88	7.32	2.32	3.10	1.53
845A.1.3.20	39.14	0.43	1.10	10.59	0.10	0.95	266.48	6.07	2.28	3.04	3.17	1.19
845A.1.3.99	34.53	0.50	1.45	8.20	0.05	0.62	248.17	5.57	2.25	2.60	2.47	1.09
845A.1.3.140	27.00	0.04	0.16	7.92	0.05	0.67	228.92	8.59	3.75	3.48	3.28	1.08
845A.1.4.20	31.11	0.26	0.85	7.27	0.10	1.40	263.99	8.89	3.37	2.93	2.44	0.95
845A.1.4.57	37.04	0.41	1.10	8.33	0.14	1.66	261.09	18.93	7.25	2.92	0.39	0.15
845A.1.4.102	35.06	0.47	1.35	6.40	0.11	1.68	157.90	7.18	4.55	2.31	2.84	1.41
845A.1.4.141	50.98	0.80	1.57	8.39	0.03	0.38	267.72	16.84	6.29	3.45	0.93	0.31
845A.1.5.18	24.68	0.06	0.26	5.24	0.03	0.57	143.99	13.08	9.08	2.58	1.76	0.78
845A.1.5.58	36.57	0.08	0.22	7.28	0.03	0.42	236.23	18.87	7.99	3.20	2.78	0.99
845A.1.5.103	33.66	0.43	1.28	8.56	0.05	0.63	263.39	4.81	1.82	3.24	2.54	0.89
845A.1.5.141	35.95	0.40	1.13	8.08	0.06	0.73	234.77	13.78	5.87	3.62	6.71	2.11
845A.2.1.21	46.20	0.40	0.87	12.77	0.04	0.31	274.43	11.87	4.33	2.88	2.00	0.79
845A.2.1.58	45.09	0.07	0.15	7.92	0.08	1.00	199.24	14.19	7.12	2.80	2.18	0.89
845A.2.1.99	29.26	0.56	1.92	7.64	0.08	1.04	212.08	4.11	1.94	2.28	2.75	1.38
845A.2.1.140	29.27	0.15	0.50	5.17	0.02	0.44	162.39	13.07	8.05	3.08	1.41	0.52
845A.2.2.8	19.87	0.40	2.02	5.63	0.03	0.46	178.98	6.61	3.69	3.32	1.71	0.59
845A.2.2.51	26.30	0.28	1.08	7.55	0.02	0.29	189.74	7.14	3.76	3.18	1.19	0.43
845A.2.2.88	35.61	0.33	0.92	9.48	0.05	0.52	221.10	11.92	5.39	2.94	1.51	0.59

Table 11 Cont. Site 845 concentration values for elements Mn, Zn, S, and Sr (µmol/g) with standard deviation and percent error.

Sample ID	Mn	std dev	% error	Zn	std dev	% error	S	std dev	% error	Sr	std dev	% error
845A.2.2.128	57.15	0.59	1.02	10.56	0.05	0.46	323.00	3.43	1.06	3.23	1.37	0.48
845A.2.3.20	23.35	0.42	1.80	6.13	0.05	0.76	311.45	21.84	7.01	2.63	0.52	0.22
845A.2.3.58	25.38	0.24	0.95	7.32	0.02	0.30	231.47	6.32	2.73	3.13	1.61	0.59
845A.2.3.99	28.04	0.12	0.44	7.01	0.10	1.45	258.15	15.67	6.07	4.58	3.56	0.89
845A.2.3.140	28.89	0.51	1.77	7.40	0.07	0.89	193.17	10.57	5.47	4.03	1.65	0.47
845A.2.4.20	40.48	0.31	0.76	8.79	0.05	0.54	187.07	9.77	5.22	3.37	4.52	1.53
845A.2.4.58	31.92	0.66	2.08	7.51	0.07	0.99	154.96	6.89	4.45	2.62	1.20	0.52
845A.2.4.98	40.95	0.48	1.18	9.89	0.08	0.82	363.34	9.66	2.66	3.48	3.27	1.07
845A.2.4.138	24.45	0.39	1.57	6.86	0.09	1.28	172.39	12.47	7.23	2.50	3.05	1.39
845A.2.5.20	23.93	0.52	2.15	6.60	0.06	0.86	214.27	4.15	1.94	3.32	2.01	0.69
845A.2.5.58	26.90	0.22	0.81	7.64	0.02	0.22	226.52	7.51	3.32	3.57	0.60	0.19
845A.2.5.98	32.84	0.87	2.66	7.95	0.08	0.98	268.48	14.50	5.40	2.73	0.46	0.19
845A.2.5.138	40.46	0.45	1.11	8.40	0.09	1.11	245.55	9.51	3.87	3.55	5.66	1.82
845A.2.6.20	48.85	0.63	1.29	9.33	0.15	1.66	321.85	18.94	5.89	2.93	2.78	1.08
845A.2.6.56	26.88	0.30	1.10	5.89	0.03	0.48	294.33	14.23	4.83	3.21	1.51	0.54
845A.2.6.98	31.13	0.30	0.96	8.16	0.09	1.10	189.12	15.20	8.04	3.18	2.96	1.06
845A.2.6.138	33.58	0.26	0.79	7.77	0.09	1.17	229.84	8.39	3.65	3.16	2.86	1.03
845A.2.7.20	42.86	0.84	1.97	8.51	0.10	1.15	284.03	6.86	2.42	2.87	2.29	0.91
845A.3.1.10	37.86	0.28	0.74	8.22	0.02	0.23	184.78	1.37	0.74	3.32	4.47	1.53
845A.3.1.50	50.12	0.80	1.61	8.64	0.02	0.23	312.09	29.99	9.61	2.84	2.02	0.81
845A.3.1.90	39.37	0.33	0.83	9.16	0.06	0.70	232.77	23.45	10.08	3.24	3.06	1.08
845A.3.1.130	44.09	0.55	1.24	6.99	0.01	0.09	235.00	9.98	4.24	3.80	1.60	0.48
845A.3.2.10	43.52	0.23	0.54	8.79	0.09	1.06	261.51	3.20	1.22	3.31	0.77	0.27
845A.3.2.50	77.16	0.67	0.86	8.21	0.12	1.48	305.44	2.23	0.73	3.02	5.26	1.99
845A.3.2.88	25.77	0.06	0.24	6.45	0.04	0.60	247.45	6.51	2.63	3.79	2.32	0.70

Table 11 Cont. Site 845 concentration values for elements Mn, Zn, S, and Sr (µmol/g) with standard deviation and percent error.

Sample ID	**Mn**	**std dev**	**% error**	**Zn**	**std dev**	**% error**	**S**	**std dev**	**% error**	**Sr**	**std dev**	**% error**
845A.3.2.130	25.66	0.08	0.33	5.80	0.01	0.15	551.65	16.11	2.92	4.05	1.80	0.51
845A.3.3.10	37.50	0.83	2.21	7.65	0.09	1.20	270.69	15.42	5.70	3.84	5.26	1.56
845A.3.3.50	39.14	0.32	0.83	8.51	0.04	0.41	204.39	4.87	2.38	3.80	2.20	0.66
845A.3.3.90	47.63	0.52	1.09	9.60	0.04	0.45	291.80	11.29	3.87	3.09	0.53	0.20
845A.3.3.130	33.95	0.16	0.46	8.89	0.09	1.02	225.48	11.64	5.16	3.80	2.54	0.76
845A.3.4.10	40.53	0.67	1.65	10.21	0.12	1.21	263.76	22.23	8.43	3.43	7.30	2.43
845A.3.4.48	42.15	0.50	1.19	9.79	0.04	0.43	322.66	10.77	3.34	3.49	2.80	0.92
845A.3.4.90	42.16	0.28	0.66	9.67	0.08	0.78	279.83	5.33	1.90	3.54	1.82	0.59
845A.3.4.132	37.45	0.37	0.99	8.93	0.09	0.97	241.81	16.20	6.70	3.43	7.00	2.33
845A.3.5.10	34.29	0.26	0.74	8.16	0.04	0.54	259.10	11.38	4.39	4.13	1.93	0.53
845A.3.5.48	29.23	0.20	0.70	6.85	0.01	0.15	244.61	14.26	5.83	2.96	3.27	1.26

Table 12. Site 849 concentration values for elements Fe, Al, Mg, and Ca (μmol/g) with standard deviation and percent error.

Sample ID	**Fe**	**std dev**	**% error**	**Al**	**std dev**	**% error**	**Mg**	**std dev**	**% error**	**Ca**	**std dev**	**% error**
849A.1.1.0	340.67	3.41	1.00	323.77	2.63	0.81	172.77	2.58	1.50	3599.63	21.19	0.59
849A.1.1.27	672.75	1.85	0.27	758.01	6.97	0.92	314.76	0.80	0.25	4492.50	56.17	1.25
849A.1.1.57	642.77	4.41	0.69	544.71	4.59	0.84	328.49	3.38	1.03	4483.76	64.69	1.44
849A.1.1.87	530.58	2.14	0.40	611.53	12.25	2.00	275.72	2.61	0.95	4881.78	53.02	1.09
849A.1.1.118	59.25	0.48	0.80	190.42	4.03	2.12	136.48	0.66	0.48	4129.70	55.86	1.35
849A.1.2.2	54.38	0.29	0.54	81.64	0.96	1.18	109.41	0.87	0.79	4228.11	34.46	0.82
849A.1.2.28	435.19	6.22	1.43	457.83	4.55	0.99	241.45	2.35	0.97	4925.06	55.70	1.13
849A.1.2.60	105.42	0.67	0.63	244.66	1.25	0.51	164.28	1.50	0.92	4888.75	33.69	0.69
849A.1.2.88	461.42	2.12	0.46	434.92	0.99	0.23	262.60	1.59	0.60	4516.25	58.59	1.30
849A.1.2.118	489.71	3.92	0.80	456.94	4.11	0.90	248.14	0.45	0.18	4805.20	36.16	0.75
849B.1.3.10	87.07	0.95	1.09	173.00	1.93	1.12	151.38	1.49	0.99	4410.15	52.08	1.18
849B.1.3.38	100.12	0.22	0.22	231.29	3.98	1.72	173.08	1.59	0.92	4267.44	37.73	0.88
849B.1.3.65	92.25	0.43	0.47	230.21	1.77	0.77	176.28	1.72	0.97	4622.52	46.83	1.01
849B.1.3.86	585.43	9.02	1.54	640.88	6.64	1.04	282.85	2.97	1.05	4628.12	82.65	1.79
849B.1.3.112	47.32	0.39	0.82	109.94	0.62	0.56	108.71	0.72	0.66	5008.06	65.56	1.31
849B.1.3.142	257.16	3.12	1.21	228.50	2.58	1.13	117.81	2.84	2.41	3364.77	66.54	1.98

Table 13. Site 848 concentration values for elements Fe, Al, and Ca (μmol/g) with standard deviation and percent error.

Sample ID	Fe	std dev	% error	Al	std dev	% error	Ca	std dev	% error
848B.1.1.3	59.90	0.27	0.44	93.29	0.66	0.71	7562.62	115.61	1.53
848B.1.1.33	111.24	0.27	0.24	113.84	2.67	2.34	7458.93	70.43	0.94
848B.1.1.63	83.21	0.34	0.41	78.15	0.39	0.50	7020.66	120.57	1.72
848B.1.1.90	129.05	0.46	0.36	123.44	1.09	0.88	6176.71	84.46	1.37
848B.1.1.120	253.92	1.56	0.61	236.84	5.62	2.37	5635.69	118.55	2.10
848B.1.1.146	119.60	0.72	0.60	125.89	1.30	1.04	5730.17	50.23	0.88
848B.1.2.0	12.04	0.06	0.50	12.26	0.25	2.07	636.31	11.90	1.87
848B.1.2.30	108.82	0.30	0.28	114.34	0.71	0.62	6873.27	124.89	1.82
848B.1.2.55	90.54	0.61	0.67	135.82	1.32	0.97	7013.84	142.76	2.04
848B.1.cc.0	99.45	0.66	0.67	120.64	1.33	1.10	6625.69	51.90	0.78
848B.2.1.0	88.35	0.74	0.83	102.92	1.13	1.10	7123.60	102.82	1.44
848B.2.1.30	86.77	0.54	0.63	109.87	0.80	0.73	7513.40	95.21	1.27
848B.2.1.56	135.27	1.39	1.03	137.07	2.30	1.68	7662.25	117.04	1.53
848B.2.1.90	92.74	1.43	1.54	82.20	0.89	1.09	8234.99	121.49	1.48
848B.2.1.122	33.14	0.61	1.85	65.29	0.72	1.10	7366.54	91.41	1.24
848B.2.1.145	23.19	0.17	0.75	49.38	0.20	0.40	7475.67	80.46	1.08
848B.2.2.0	34.53	0.56	1.63	50.13	0.68	1.35	8028.13	103.44	1.29
848B.2.2.31	29.37	0.34	1.15	56.95	0.41	0.73	7754.15	45.06	0.58
848B.2.2.56	134.53	1.11	0.83	145.00	1.16	0.80	8170.49	145.35	1.78
848B.2.2.94	82.12	0.21	0.26	90.46	0.28	0.31	7960.23	133.55	1.68
848B.2.2.122	39.41	0.40	1.01	70.09	0.60	0.85	7419.26	158.62	2.14
848B.2.2.145	62.69	0.84	1.33	60.57	1.77	2.93	7629.78	59.21	0.78
848B.2.3.0	46.47	0.14	0.31	54.58	1.11	2.03	7118.83	95.34	1.34
848B.2.3.31	43.52	0.31	0.72	239.38	7.76	3.24	7167.75	69.03	0.96

Table 13 Cont. Site 848 concentration values for elements Fe, Al, and Ca (μmol/g) with standard deviation and percent error.

Sample ID	Fe	std dev	% error	Al	std dev	% error	Ca	std dev	% error
848B.2.3.60	103.10	1.23	1.20	133.77	1.61	1.20	7115.90	114.70	1.61
848B.2.3.90	125.81	0.65	0.51	103.68	0.63	0.60	7637.58	89.58	1.17
848B.2.3.123	60.34	0.65	1.08	94.41	0.78	0.82	6767.19	77.68	1.15
848B.2.3.145	113.44	0.97	0.86	80.63	1.48	1.84	7610.42	90.99	1.20
848B.2.4.0	104.91	1.14	1.09	59.91	0.63	1.05	6082.69	50.39	0.83
848B.2.4.32	28.28	0.16	0.58	44.46	0.90	2.03	7210.64	90.81	1.26
848B.2.4.66	30.75	0.28	0.90	41.51	0.10	0.25	7381.56	95.86	1.30
848B.2.4.90	71.09	0.66	0.92	62.88	0.48	0.76	6313.60	54.41	0.86
848B.2.4.123	179.82	0.94	0.52	154.97	2.99	1.93	6635.62	50.22	0.76
848B.2.4.145	71.54	0.62	0.87	47.59	0.14	0.29	6261.45	37.88	0.61
848B.2.5.0	76.89	0.75	0.98	57.27	0.63	1.10	7156.43	108.39	1.51
848B.2.5.31	106.06	0.62	0.58	106.85	1.50	1.40	7014.61	82.75	1.18
848B.2.5.60	58.56	0.42	0.72	56.57	0.21	0.38	6950.45	88.84	1.28
848B.2.5.90	71.47	0.12	0.17	81.75	0.85	1.03	7333.19	116.05	1.58
848B.2.5.122	141.68	61.39	43.33	1744.50	151.71	8.70	1356.98	407.79	30.05
848B.2.5.146	76.09	0.60	0.79	65.28	1.14	1.74	7432.92	87.28	1.17
848B.2.6.0	93.53	0.97	1.04	60.78	1.39	2.28	7317.78	65.92	0.90
848B.2.6.31	97.92	0.21	0.22	67.71	0.92	1.36	7145.44	68.86	0.96
848B.2.6.56	91.40	0.80	0.88	74.55	2.14	2.87	6521.79	105.06	1.61
848B.2.6.90	209.58	1.82	0.87	144.74	0.78	0.54	7012.13	112.55	1.61
848B.2.6.122	247.05	2.07	0.84	180.70	2.21	1.22	6957.05	62.39	0.90
848B.2.7.0	223.83	1.35	0.60	98.37	1.72	1.75	6858.73	86.28	1.26
848B.2.7.32	61.14	0.15	0.24	86.97	0.62	0.71	7615.34	97.26	1.28
848B.2.7.56	50.35	0.28	0.56	52.45	0.70	1.34	7755.65	106.44	1.37

Table 13 Cont. Site 848 concentration values for elements Fe, Al, and Ca (µmol/g) with standard deviation and percent error.

Sample ID	**Fe**	**std dev**	**% error**	**Al**	**std dev**	**% error**	**Ca**	**std dev**	**% error**
848B.2.cc.0	90.58	1.53	1.69	57.10	1.37	2.39	7403.00	112.37	1.52
848B.3.1.0	115.27	1.62	1.41	90.20	0.76	0.85	5065.20	57.81	1.14
848B.3.1.30	140.52	1.41	1.01	91.68	2.44	2.66	5362.82	71.01	1.32
848B.3.1.66	146.11	1.39	0.95	94.87	1.92	2.03	5400.53	42.90	0.79
848B.3.1.90	124.13	1.01	0.82	71.36	1.73	2.42	5572.32	110.22	1.98

Table 14. Site 853 concentration values for elements Fe, Al, Mg, and Ca (µmol/g) with standard deviation and percent error.

Sample ID	Fe	std dev	% error	Al	std dev	% error	Mg	std dev	% error	Ca	std dev	% error
853B.1.1.20	56.54	0.54	0.96	121.76	1.26	1.03	134.46	0.64	0.48	4508.40	64.24	1.42
853B.1.1.35	55.32	0.19	0.34	111.99	1.73	1.54	124.16	1.45	1.17	4585.86	36.16	0.79
853B.1.1.50	53.92	0.21	0.39	137.87	1.39	1.01	112.27	0.35	0.31	5248.60	61.98	1.18
853B.1.1.66	890.50	10.35	1.16	910.86	16.63	1.83	424.15	4.06	0.96	4177.61	39.71	0.95
853B.1.1.83	925.39	7.28	0.79	977.77	10.32	1.06	475.42	3.57	0.75	4189.50	65.32	1.56
853B.1.1.97	370.99	1.97	0.53	366.65	4.47	1.22	211.84	2.74	1.29	4863.91	63.27	1.30
853C.1.1.0	596.25	2.38	0.40	652.55	6.36	0.97	325.21	2.96	0.91	4568.23	64.05	1.40
853B.1.1.112	505.65	3.38	0.67	979.91	18.16	1.85	211.57	1.79	0.85	125.51	2.13	1.69
853C.1.1.15	714.75	4.15	0.58	748.98	13.02	1.74	359.42	2.74	0.76	4355.34	52.32	1.20
853B.1.1.127	694.10	0.75	0.11	891.30	6.48	0.73	741.77	4.86	0.66	1637.31	22.03	1.35
853C.1.1.30	47.14	0.27	0.58	124.04	1.30	1.05	96.65	0.78	0.80	4849.28	44.06	0.91
853B.1.1.142	99.14	0.63	0.64	261.92	2.65	1.01	161.67	1.33	0.82	4751.64	61.15	1.29
853C.1.1.45	106.99	0.25	0.24	197.05	1.58	0.80	186.35	1.50	0.81	4573.36	50.58	1.11
853B.1.2.0	811.17	5.27	0.65	756.18	12.37	1.64	390.69	4.30	1.10	4300.43	67.47	1.57
853B.1.2.20	76.16	0.57	0.75	193.01	1.65	0.85	141.55	0.95	0.67	4061.70	48.82	1.20
853C.1.1.60	504.19	3.88	0.77	931.77	11.02	1.18	207.82	2.29	1.10	111.76	1.78	1.59
853C.1.1.73	1045.37	8.32	0.80	1334.10	10.57	0.79	1140.80	12.41	1.09	2241.34	42.70	1.90
853B.1.2.36	825.17	5.73	0.69	782.37	15.98	2.04	454.62	2.23	0.49	3927.17	16.06	0.41
853B.1.2.50	617.06	8.67	1.41	639.78	10.45	1.63	338.38	6.99	2.07	4969.21	78.89	1.59
853C.1.1.90	69.09	0.95	1.38	148.56	2.91	1.96	130.78	3.35	2.57	4574.46	80.49	1.76
853B.1.2.65	37.14	0.28	0.75	112.72	2.06	1.83	129.80	0.22	0.17	4951.96	60.74	1.23
853C.1.1.105	692.37	5.52	0.80	648.92	5.43	0.84	344.52	4.79	1.39	4578.07	54.41	1.19
853B.1.2.80	64.07	0.58	0.90	117.43	1.43	1.21	122.02	2.42	1.99	107.09	3.18	2.97
853C.1.1.120	676.09	4.54	0.67	607.91	10.48	1.72	364.06	4.04	1.11	4688.31	45.15	0.96
853B.1.2.95	591.86	10.30	1.74	584.40	4.36	0.75	308.12	1.22	0.40	4487.89	53.02	1.18
853C.1.1.135	423.51	0.62	0.15	448.59	8.42	1.88	251.78	1.56	0.62	5155.98	37.13	0.72

Table 14 Cont. Site 853 concentration values for elements Fe, Al, Mg, and Ca (μmol/g) with standard deviation and percent error.

Sample ID	**Fe**	**std dev**	**% error**	**Al**	**std dev**	**% error**	**Mg**	**std dev**	**% error**	**Ca**	**std dev**	**% error**
853B.1.2.111	405.56	2.75	0.68	364.99	1.67	0.46	235.57	2.04	0.87	4733.21	29.20	0.62
853B.1.2.125	542.20	7.20	1.33	560.00	2.06	0.37	290.01	0.32	0.11	5418.51	96.50	1.78
853B.1.2.140	88.66	0.97	1.10	151.78	1.83	1.21	141.61	2.09	1.48	3822.51	47.56	1.24
853B.1.3.1	631.71	1.39	0.22	632.89	5.12	0.81	371.80	0.66	0.18	4710.87	45.83	0.97
853B.1.3.17	677.18	2.77	0.41	752.99	7.12	0.95	360.78	4.10	1.14	4205.35	42.04	1.00
853B.1.3.30	536.33	2.44	0.45	637.26	6.11	0.96	344.10	1.21	0.35	4632.03	40.48	0.87
853B.1.3.47	777.15	0.99	0.13	797.07	5.70	0.72	457.19	2.40	0.53	3869.17	17.86	0.46
853B.1.3.58	491.44	2.72	0.55	490.11	6.24	1.27	253.67	2.24	0.88	4715.16	52.92	1.12
853B.1.3.78	592.64	3.76	0.63	566.10	7.04	1.24	330.77	1.48	0.45	4361.58	53.11	1.22
853B.1.3.93	463.95	2.18	0.47	462.70	5.72	1.24	277.98	1.67	0.60	4938.37	51.86	1.05
853B.1.3.107	418.27	2.75	0.66	797.73	14.40	1.81	169.59	1.83	1.08	90.43	0.22	0.24

Table 15. Site 845 concentration values for elements Fe, Al, Mg, and Ca (µmol/g) with standard deviation and percent error.

Sample ID	Fe	std dev	% error	Al	std dev	% error	Mg	std dev	% error	Ca	std dev	% error
845A.1.1.140	760.50	6.06	0.01	1253.23	8.63	0.69	760.80	1.06	0.14	400.56	2.32	0.58
845A.1.2.20	735.40	9.05	0.01	1116.09	1.56	0.14	814.96	7.82	0.96	437.29	5.53	1.26
845A.1.2.58	641.67	5.31	0.01	1176.53	9.77	0.83	673.41	9.39	1.39	378.01	3.34	0.88
845A.1.2.99	655.78	6.80	0.01	1308.38	12.44	0.95	609.53	6.78	1.11	418.59	6.47	1.55
845A.1.2.140	621.05	12.14	0.02	1285.75	17.77	1.38	479.85	3.10	0.65	191.61	3.86	2.02
845A.1.3.20	688.17	15.63	0.02	1181.34	21.48	1.82	700.71	12.17	1.74	363.65	3.90	1.07
845A.1.3.99	917.47	20.51	0.02	1427.91	16.58	1.16	738.12	7.17	0.97	281.74	4.09	1.45
845A.1.3.140	749.64	2.48	0.00	1471.87	11.47	0.78	745.02	5.48	0.74	589.64	4.72	0.80
845A.1.4.20	873.49	22.27	0.03	1278.59	0.85	0.07	722.37	7.64	1.06	427.05	2.51	0.59
845A.1.4.57	666.50	13.16	0.02	1179.01	16.59	1.41	657.91	12.67	1.93	453.25	2.25	0.50
845A.1.4.102	528.09	2.86	0.01	1548.87	2.76	0.18	545.41	1.49	0.27	345.60	4.12	1.19
845A.1.4.141	729.67	8.04	0.01	1173.93	11.18	0.95	853.44	12.98	1.52	580.48	7.81	1.34
845A.1.5.18	436.86	0.96	0.00	853.95	8.60	1.01	474.08	0.64	0.14	359.57	3.51	0.98
845A.1.5.58	712.33	6.36	0.01	1375.67	8.61	0.63	749.22	2.95	0.39	432.01	7.28	1.69
845A.1.5.103	836.45	10.75	0.01	1350.43	14.16	1.05	795.54	8.61	1.08	412.34	5.62	1.36
845A.1.5.141	858.80	6.86	0.01	1458.04	7.46	0.51	749.47	8.57	1.14	491.78	0.73	0.15
845A.2.1.21	649.92	9.32	0.01	1125.92	11.59	1.03	767.38	14.38	1.87	348.50	6.08	1.74
845A.2.1.58	509.54	0.83	0.00	935.26	3.58	0.38	661.79	2.14	0.32	497.74	4.61	0.93
845A.2.1.99	493.08	10.46	0.02	1077.39	17.65	1.64	532.27	11.20	2.10	366.39	7.55	2.06
845A.2.1.140	509.94	3.06	0.01	1321.88	5.08	0.38	512.33	2.24	0.44	766.28	16.43	2.14
845A.2.2.8	689.15	12.91	0.02	1418.38	19.23	1.36	549.36	3.65	0.66	932.62	10.03	1.08
845A.2.2.51	614.89	3.21	0.01	1159.05	17.83	1.54	689.56	4.48	0.65	566.04	2.77	0.49
845A.2.2.88	757.80	8.93	0.01	1189.03	2.87	0.24	784.72	5.68	0.72	386.40	5.32	1.38

Table 15 Cont. Site 845 concentration values for elements Fe, Al, Mg, and Ca (µmol/g) with standard deviation and percent error.

Sample ID	Fe	std dev	% error	Al	std dev	% error	Mg	std dev	% error	Ca	std dev	% error
845A.2.2.128	768.13	12.09	0.02	1151.95	4.26	0.37	861.97	9.82	1.14	453.87	5.91	1.30
845A.2.3.20	670.95	9.09	0.01	1019.85	1.64	0.16	610.17	9.91	1.62	377.80	6.71	1.78
845A.2.3.58	753.38	6.56	0.01	1467.35	14.80	1.01	687.29	7.91	1.15	638.56	8.72	1.37
845A.2.3.99	517.46	7.74	0.01	1030.23	4.07	0.40	591.94	1.84	0.31	1858.19	9.12	0.49
845A.2.3.140	513.36	12.21	0.02	989.78	9.39	0.95	590.03	5.46	0.93	1421.50	13.56	0.95
845A.2.4.20	643.55	0.49	0.00	1168.97	24.48	2.09	737.63	7.47	1.01	483.41	3.99	0.83
845A.2.4.58	476.41	4.38	0.01	861.22	7.37	0.86	560.97	8.99	1.60	456.41	5.20	1.14
845A.2.4.98	719.88	9.98	0.01	1112.19	12.39	1.11	797.58	7.74	0.97	723.06	8.14	1.13
845A.2.4.138	433.19	5.27	0.01	746.80	10.28	1.38	506.87	6.79	1.34	652.71	7.91	1.21
845A.2.5.20	570.14	4.72	0.01	964.86	10.09	1.05	472.64	2.42	0.51	1063.05	18.02	1.69
845A.2.5.58	635.09	4.27	0.01	1238.88	2.87	0.23	697.19	9.31	1.33	865.18	5.17	0.60
845A.2.5.98	617.83	14.98	0.02	896.07	11.17	1.25	507.38	4.14	0.82	357.11	2.58	0.72
845A.2.5.138	655.28	6.87	0.01	1139.07	2.57	0.23	654.75	13.29	2.03	768.89	10.29	1.34
845A.2.6.20	811.83	12.19	0.02	1302.15	3.80	0.29	851.90	2.21	0.26	375.20	6.10	1.62
845A.2.6.56	743.45	4.57	0.01	1407.69	3.65	0.26	648.07	2.55	0.39	406.74	5.06	1.25
845A.2.6.98	560.41	7.61	0.01	1169.09	9.80	0.84	631.17	7.23	1.15	667.85	6.65	1.00
845A.2.6.138	602.93	6.21	0.01	1179.12	27.32	2.32	652.18	5.78	0.89	647.33	8.24	1.27
845A.2.7.20	708.98	7.71	0.01	1181.11	14.09	1.19	708.22	10.44	1.47	440.89	2.47	0.56
845A.3.1.10	457.12	5.54	0.01	932.36	6.08	0.65	633.87	4.22	0.67	1020.82	8.20	0.80
845A.3.1.50	605.18	9.25	0.02	973.93	7.59	0.78	721.53	6.02	0.83	506.86	13.85	2.73
845A.3.1.90	668.02	4.97	0.01	1250.90	9.81	0.78	763.55	3.51	0.46	507.28	3.82	0.75
845A.3.1.130	510.75	2.77	0.01	1139.95	10.59	0.93	604.95	4.19	0.69	1035.69	14.05	1.36
845A.3.2.10	595.96	4.00	0.01	1021.53	3.99	0.39	665.82	2.08	0.31	496.54	4.57	0.92
845A.3.2.50	534.04	5.72	0.01	986.65	9.50	0.96	690.85	7.17	1.04	638.08	7.64	1.20
845A.3.2.88	570.11	6.09	0.01	1282.07	14.68	1.15	634.68	1.73	0.27	1018.04	2.15	0.21

Table 15 Cont. Site 845 concentration values for elements Fe, Al, Mg, and Ca (μmol/g) with standard deviation and percent error.

Sample ID	Fe	std dev	% error	Al	std dev	% error	Mg	std dev	% error	Ca	std dev	% error
845A.3.2.130	624.02	1.04	0.00	1058.98	8.86	0.84	519.04	5.20	1.00	1585.31	12.12	0.76
845A.3.3.10	540.08	6.75	0.01	1170.79	6.99	0.60	617.12	4.92	0.80	1241.80	13.20	1.06
845A.3.3.50	565.73	5.17	0.01	1342.71	18.52	1.38	757.55	4.33	0.57	860.01	2.11	0.25
845A.3.3.90	600.35	7.01	0.01	1224.38	15.38	1.26	774.73	10.37	1.34	418.66	2.63	0.63
845A.3.3.130	550.14	1.70	0.00	1264.14	2.90	0.23	712.46	4.92	0.69	834.92	10.92	1.31
845A.3.4.10	571.83	14.97	0.03	1214.58	22.62	1.86	774.07	6.99	0.90	834.24	18.71	2.24
845A.3.4.48	632.35	6.57	0.01	1296.10	5.15	0.40	765.47	6.30	0.82	599.43	4.23	0.71
845A.3.4.90	615.38	5.55	0.01	1477.75	3.14	0.21	801.29	11.17	1.39	566.33	7.65	1.35
845A.3.4.132	597.61	9.07	0.02	1525.79	19.39	1.27	736.60	11.15	1.51	609.77	6.82	1.12
845A.3.5.10	585.37	4.37	0.01	1298.08	5.10	0.39	756.01	4.04	0.53	1135.79	3.28	0.29
845A.3.5.48	575.06	8.41	0.01	1142.06	7.29	0.64	605.48	1.89	0.31	337.25	4.99	1.48

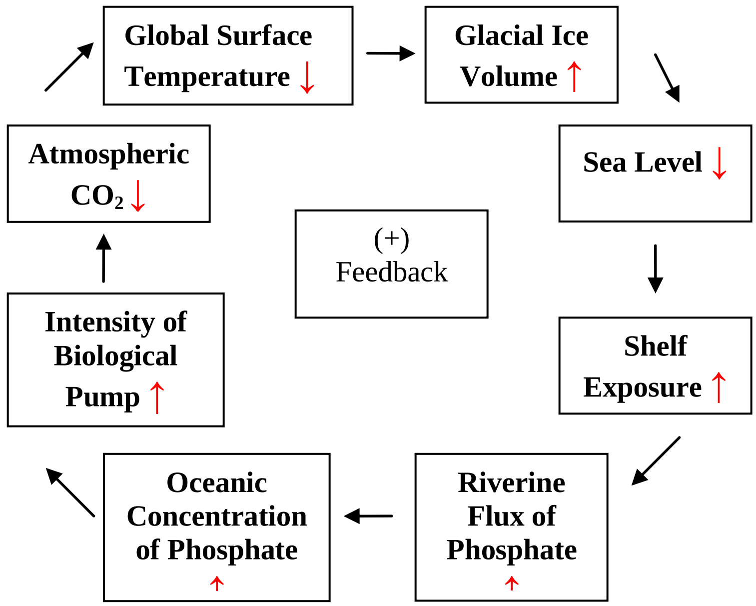

Fig 1. Visual representation of the SNH. Up and down arrows within the boxes indicate either an increase or decrease.

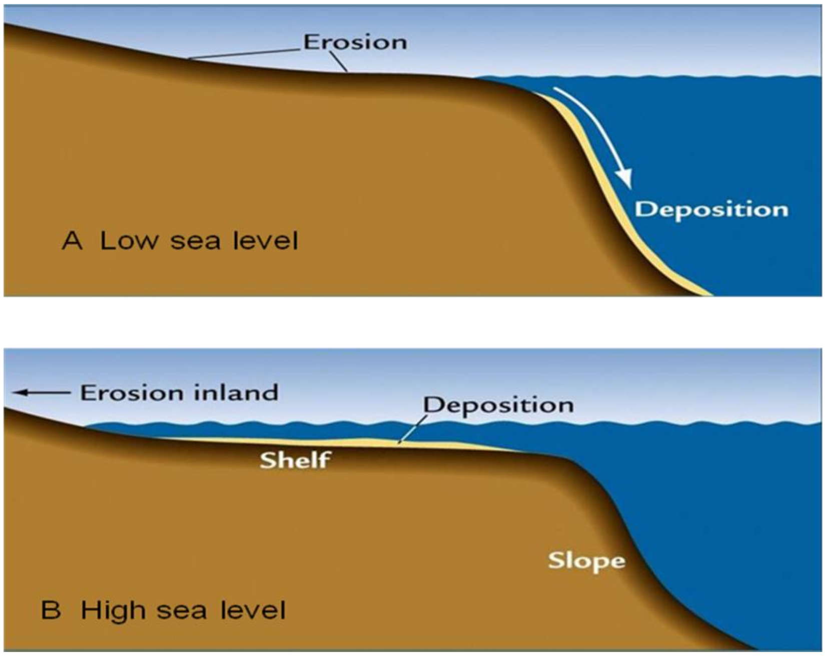

Fig 2. A visual depiction of how continental shelves and margins appear during (A) glacials and (B) interglacials. (Ruddiman, 2008).

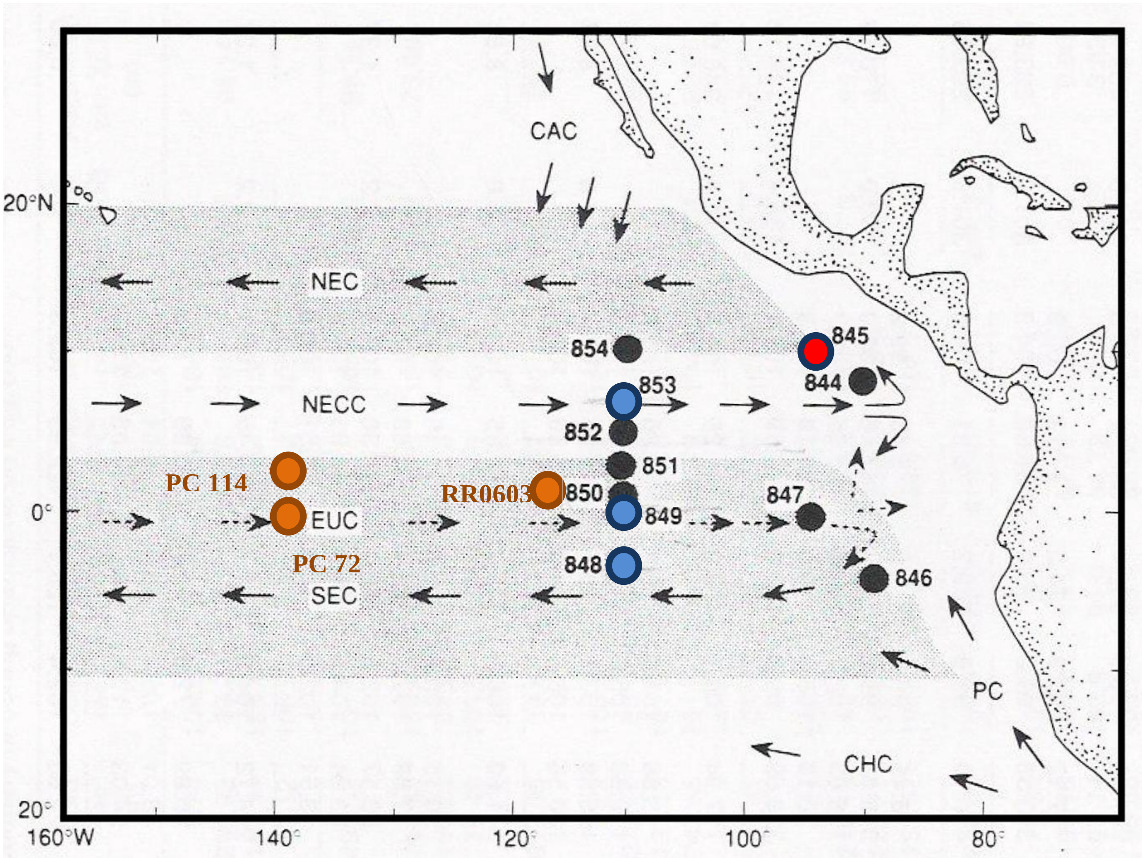

Fig 3. Map of EEP sites (red, blue), and CEP sites (orange). EEP site 845 is red to highlight that it is a basin site. All other sites are part of ODP Leg 138 but not analyzed in this study. Arrows and abbreviations (CHC, PC, SEC, EUC, NECC, NEC, and CAC) refer to names of ocean currents and their flow direction.

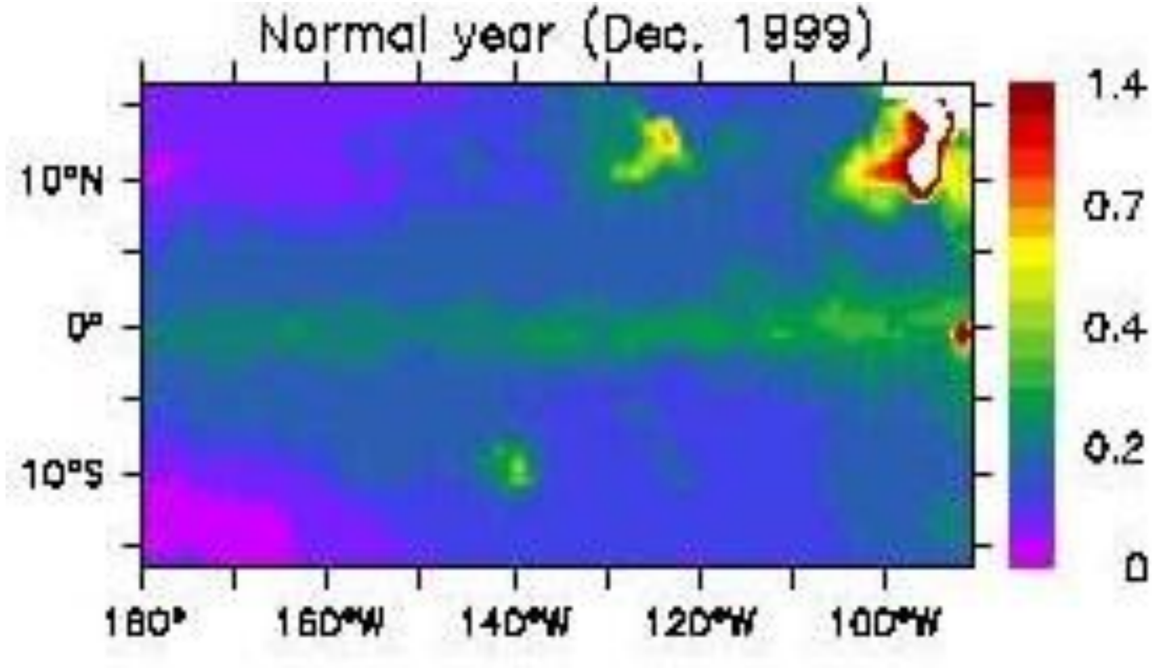

Fig 4. Image data of surface chlorophyll a production for a normal year. Productivity gradient values (right) are in units of mg m^{-3} (SeaWiFS data, NASA, 2005).

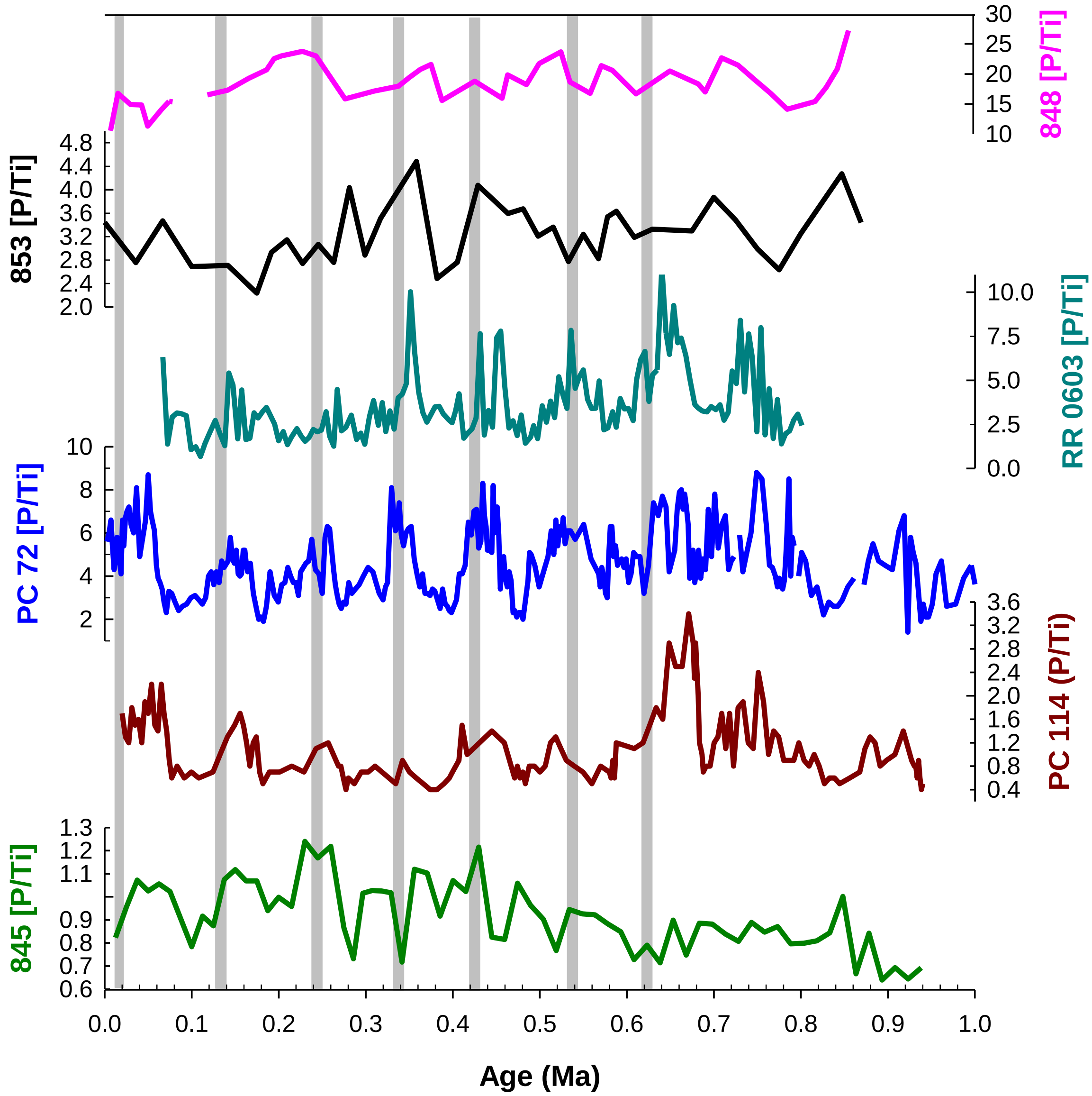

Fig 5. P/Ti (g/g) proxy vs. age for Leg 138 sites (minus 849) as well as three CEP sites. Gray bars indicate approximate timing of glacial terminations (Lisiecki and Raymo, 2005). Sites follow the same order of the modern ocean chlorophyll gradient (top to bottom is high to low, respectively).

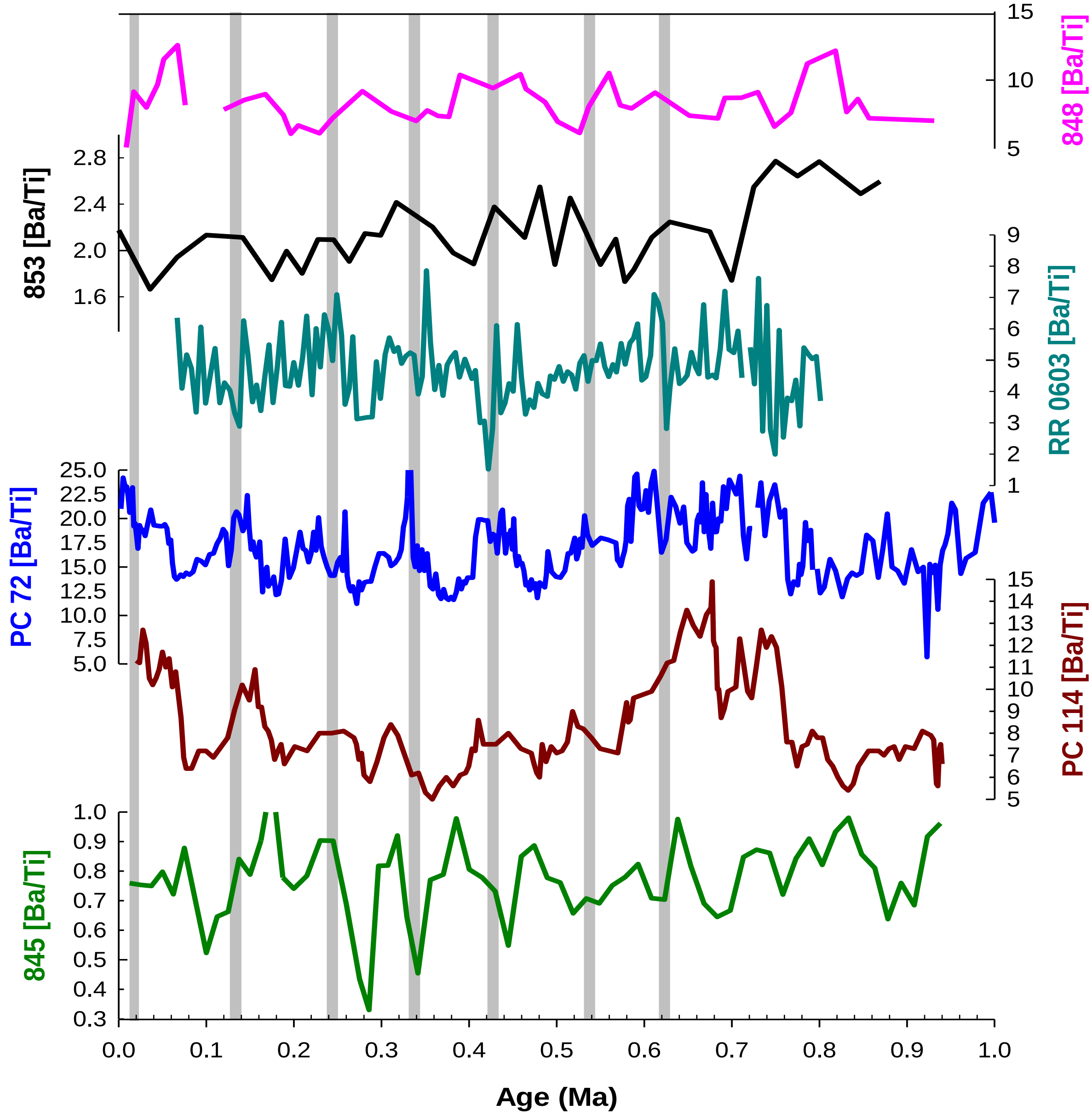

Fig 6. Ba/Ti (g/g) proxy vs. age for Leg 138 sites (minus 849) as well as three CEP sites. Gray bars indicate approximate timing of glacial terminations (Lisiecki and Raymo, 2005). Sites follow the same order of the modern ocean chlorophyll gradient (top to bottom is high to low, respectively).

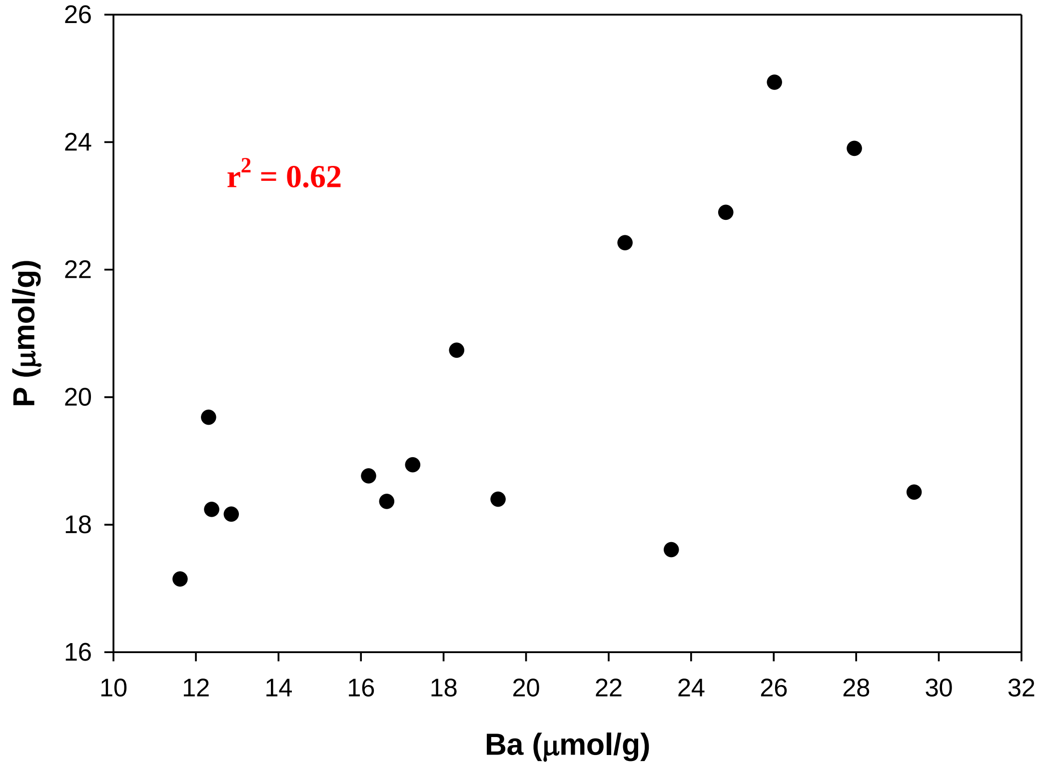

Fig 7. P vs. Ba cross plot for ODP Site 849.

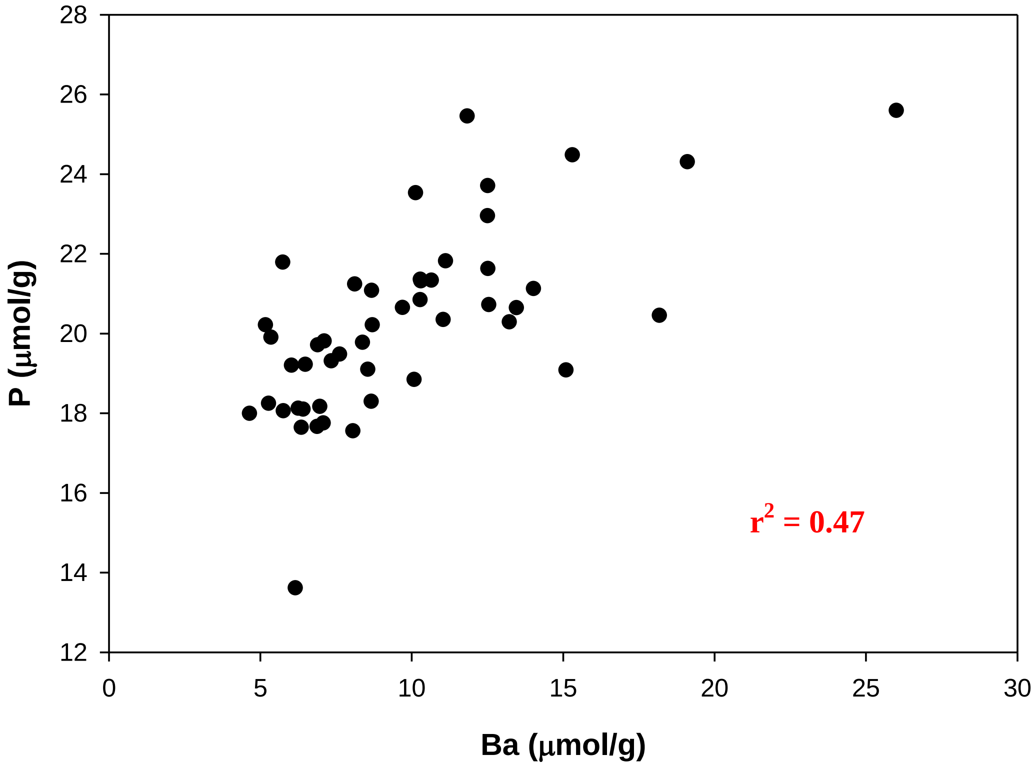

Fig 8. P vs. Ba cross plot for ODP Site 848.

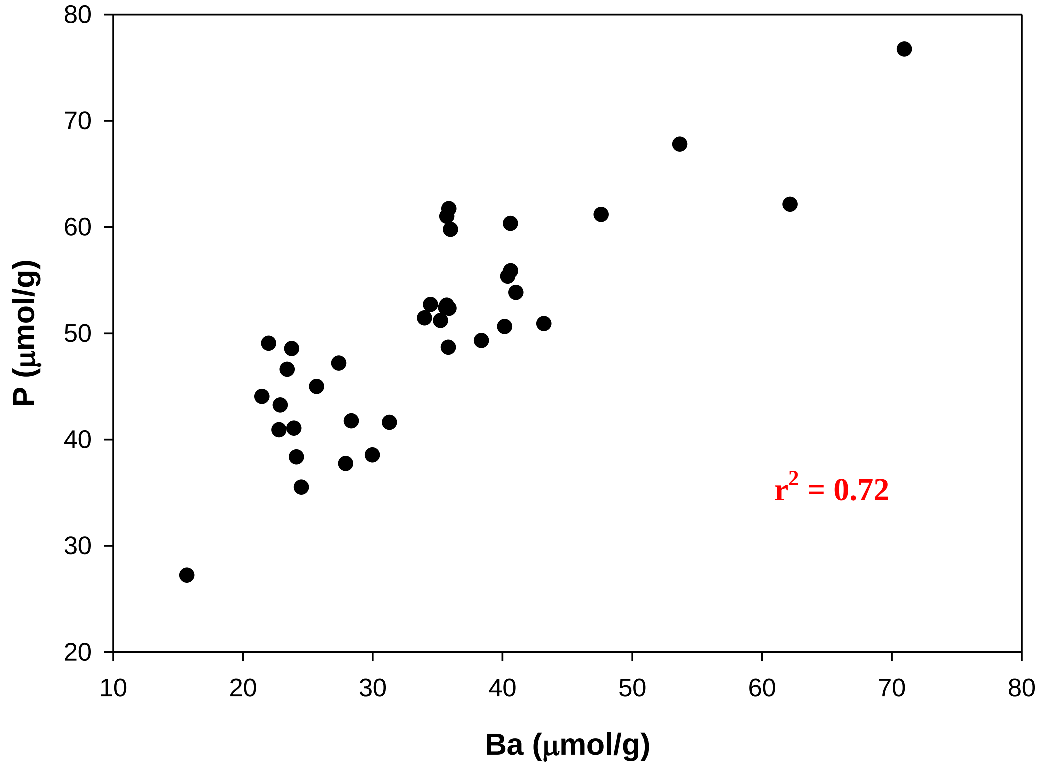

Fig 9. P vs. Ba cross plot for ODP Site 853.

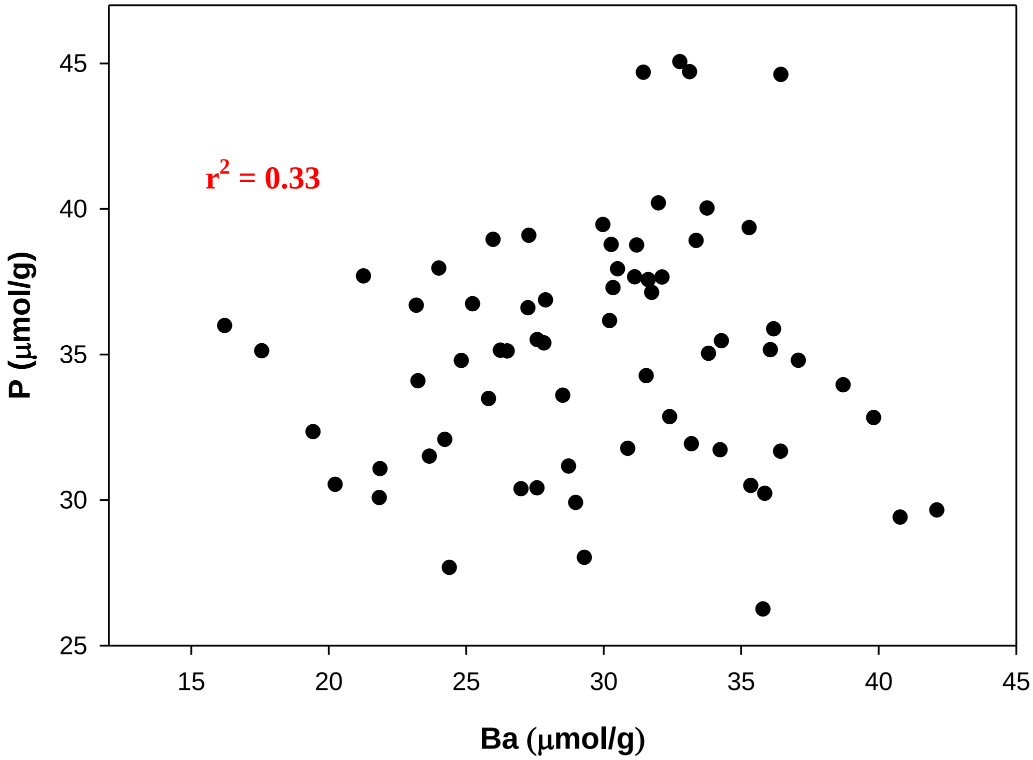

Fig 10. P vs. Ba cross plot for ODP Site 845.

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EDUCATION

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GRANTS

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-Testing the Shelf-Nutrient Hypothesis by Examining the Oceanic Phosphorus Cycle on Glacial Timescales. Gabriel Filippelli (sole PI)
National Science Foundation (NSF) 4/05-4/09 ($300,000)

Research Presentation Grant:
-Awarded to present research at the AGU Chapman Conference on Abrupt Climate Change
Angela Robertson and Gabriel Filippelli (PIs)
American Geophysical Union (AGU) June 2009 ($200)

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-Assisted teaching in SMOGEE: Students as Mentors and Owners of Geoscience and Environmental Education: The Global Warming Road Show, Fall 2008
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